

The Provision of Computer Aided Product Data Management Functions for Small and Medium Enterprises

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WHAKATAUKI

He aha te mea nui o te Ao?

He tangata, he tangata, he tangata.

Abstract

This thesis spans the cusp of the 20th and 21st centuries when enterprises were making the transition from the use of paper based to digitally based tools and methodologies to support the design and manufacture of new products. This transition occurred during a period when the globalisation of these activities was driven by the introduction of new, so-called “Information Technologies”. During this period, software vendors introduced products to cater for the new demand for the management of increasing amounts of digital data created by computer-based tools and methods. Product Data Management systems are one such example and are the focus of this thesis. Larger enterprises have embraced these technologies and the benefits from such systems are now apparent. However, the uptake of these technologies by Small and Medium sized Enterprises (SMEs) is low by comparison.

The need for data management products was driven by larger enterprises and the underlying research behind these tools and methods followed, rather than led, their introduction. As a consequence, tools and methods were proposed and implemented without due regard to the underlying concepts, nor was consideration given to how such tools and methodologies would be utilised by enterprises that varied in a multitude of ways. This area of research is important because SMEs comprise the majority of New Zealand and global enterprises. There is a need to develop suitable computer-based tools and methods to manage data to ensure SMEs can compete in an environment that is increasingly based on the creation and communication of digital data.

This thesis seeks to contribute to the field of product data management in two ways;

- Firstly, a fundamental conceptual model describing data classes and interactions by enterprises performing product development is developed.
- Secondly, the developed model is used to underpin the design, development and implementation of a novel method for managing data created and used by SMEs.

Suggestions for further development of the model and method will be made at the conclusion of the thesis.

Acknowledgements

Thank you. You know who you are.

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Introduction

Methods to record symbols to represent data have been known since sometime in the late 4th Millennium BC (Robinson, 1995, pp.11). However, during the last 40 years or so, we have witnessed a development that will forever change how humans communicate: that is, people have been recording and communicating symbols in an electronic format. Consequently, the development and introduction of so-called Information Technologies (IT) has necessitated the development of new tools and methods to manage the ever-increasing types and volumes of digital data created.

In 2001, enterprises that regularly used computers generated almost all of New Zealand's private sector economic activity (Te Tari Tatau, 2002, pp.13). Not only was digital data created by these enterprises, many contributors to the economy such as manufacturing firms relied heavily on the ability to communicate this data to support their business processes (Te Tari Tatau, 2002, pp.26).

In enterprises that develop new products the data created are essential elements of the design process. The strategic, tactical and operational management of this data can lead to shorter product development time to market and hence to a competitive advantage in the marketplace (Liu and Xu, 2001). Therefore, those organisations that successfully manage the creation and communication of data may gain significant advantages and increase their chances of survival.

In the engineering sector, early examples of the use of computer based Product Data Management (PDM) systems to manage data were in the form of dedicated in-house software used to manage engineering drawing databases (Bozdoc, 2000). From this beginning, the use of similar software was expanded to encompass the management of the computer generated equivalent of drawings: Computer Aided Design (CAD) files. The software was further developed to assist in the management of functions associated with the files such as revisions, versioning and document release control. The potential of the software to manage other data associated with the process soon followed. More recently, the requirement to share data between applications, both internal and external to an organisation, has seen increased integration between computer programs with different functions and the data they share.

Sophisticated Commercial Off The Shelf (COTS) software is now predominantly utilised for managing this data.

However, while larger enterprises have the resources to acquire and implement sophisticated software to manage the myriad of data created, Small and Medium-Sized Enterprises (SMEs) do not (Shaw, Aitchison *et al*, 1999, Whybrew, Shaw *et al*, 2001). In order to offer the same advantages to SMEs as are afforded to larger organisations, through their ability to utilise PDM systems, this thesis investigates the development of software based PDM functions suitable for smaller enterprises. The ability for SMEs to have access to PDM functions is important, not only to New Zealand (where the majority of enterprises can be classified as SMEs by world standards (Manatū Ōhanga, 2003, pp.4)) but also internationally.

The Investigation

Nature and scope

The impetus for the research described in this thesis was generated from the conclusions reached from a survey of New Zealand enterprises as part of a Public Good Science Fund (PGSF) research programme entitled “Rapid Product Development for World Class Manufacturing”. A summary of the conclusions reached from the survey is discussed in Chapter One: a copy of the technical report (Shaw *et al*, 1999) detailing the results from the survey is contained in Appendix One.

From the conclusions it was evident that most, but not all, larger enterprises in the survey were using data management software as a tool to support the development of new products. In contrast, smaller enterprises were unlikely to be utilising commercially available computer based methods to manage their data. The managers of the smaller enterprises were aware that their enterprises could benefit from managing data more effectively, but cited financial costs (e.g. purchase, implementation, maintenance and operation), lack of human resources and the New Zealand product development environment as factors that limited the uptake of these tools.

Consequently, a potential area for research was identified. This was the need for the development of two new types of knowledge. That is, new knowledge and understanding

about the characteristics of SMEs that employ methods to identify and manage data created in computer aided product development processes, as well as new knowledge of how to process the data more effectively.

Method

The method to develop this new knowledge of systems can be summarised as follows:

- Identify the shortcomings in the existing knowledge and understanding of the system(s)
- Model the environment of the system(s) to generate new knowledge and understanding of the process
- Apply the new knowledge and understanding of the process to generate new knowledge of processes that are likely to be effective in the system
- Investigate theoretically and experimentally whether the new processes can be implemented
- Conclude the efficacy of the generated knowledge and understanding.

The justification for the choice of this method is that it has been proven as a basis for the generation and application of new knowledge in the discipline of mechanical engineering. This is evidenced by the number of successful PhD's theses produced in the Department of Mechanical Engineering using this approach.

The shortcomings of existing systems were identified through a literature review. Several themes were highlighted as a result of the survey which, together with the author's knowledge of product development process practices, formed the focus of a literature search. The themes were;

- the development of typologies for computer based product data management systems,
- the benefits and difficulties associated with the implementation of such systems; both in general, and in SME environments,
- the models used by people, organisations and product development processes to classify and represent data, and

- the methods used to manage the relationships between types of data in a product development process.

A literature review of these themes is presented in Chapter Two. A select bibliography with suggested further reading around these themes is contained in Appendix Two; the inclusion of this literature is important because the functions that underpin PDM systems draw on the research findings from more than one discipline. (e.g. the underlying principles of computer hardware and software: principles of computer based data processing: the concepts of data, information and knowledge: etc.).

From the review of the literature I concluded that, while there was a wealth of research associated with enabling technologies for individual functions that comprise PDM systems, there was a lack of research that places the PDM systems within wider contexts. That is, little consideration was found to have been given, by the PDM research community, to the relationships between classes of data, data users, processes utilising data and to the impact that these relationships have on enterprise structures and hence on the development of the functions and technologies for PDM systems. The review also found that due to the inherent logical structure of commercially available PDM software packages, the ability of these systems to support the abstraction of other information pertaining to the product development process was restricted.

A review of the methods used to manage data throughout the product development process revealed that current systems required the interrelationships between data to be predetermined at the system design stage for all workflow functions. This predetermination is possible only when the product development process is mature. However, from the survey, it was clear that in most SMEs the product development processes were not of this nature.

I concluded that it was desirable to seek a new method to manage data throughout a product development process that did not require the predetermination of data types, classes and interrelationships; and thus the aims of the research evolved.

The first aim of this research was to develop a conceptual model of the processes that create digital data during a product development process. This knowledge was necessary, as 1) it is required to support the development of PDM functions using emerging technologies and 2)

current models did not consider the relationships between classes of data, data users, processes utilising data and their interrelationship with enterprise systems. To develop a model that accounted for these relationships I integrated the models of Ackoff and Emery (Ackoff and Emery, 1972) (communications between people), Beer (Beer, 1981) (the structure of organisations), Hales (Hales, 1986) (product development process phases), and Garner (Garner, 1991) (organisational integration).

The above models were selected for the following reasons:

- The Ackoff and Emery model was selected to model communications between people as it is the only representation that considers the functions performed by people as purposeful systems, which is based on a scientific approach and uses hard operational definitions.
- The Beer model was selected as it is the only model that completely represents the integrated set of necessary interacting functions for organisations to remain viable in their environments.
- Both of the above models had previously been successfully utilised in a Doctoral research thesis that modelled the interactions between roles in an organisation (Garner, 1991).
- Hales' model, of the engineering design process, was selected as it was the first model of the design process that was based on the analysis of data recorded from practice. Hales' model related to the design of a one-of-a-kind artefact, Dallas extended the model to represent a product development process. The extended model was subsequently used to research product development processes in a New Zealand SME (Dallas, 1998, Hales, 1986, Hales, 2004,).

The development and justification of the integrated model is explained in Chapter Three. Where necessary the meanings attached to particular key words used in that chapter have been established and are presented in Appendix Three.

Utilising the developed model, data and metadata generated through the relationships between classes of data, data users, processes utilising data and enterprise systems were established: this was a necessary step in order for new tools and methods to manage the data to be developed.

Three further aims of this thesis, necessary for the development of new computer based methods and tools to manage data, that are suitable for SMEs, were pursued:

- The investigation of the feasibility of automatically extracting types of metadata (identified from the integrated model) from the operating system of the computing environment to describe the state of the system at any instant. This is an important feature for SMEs as it can potentially allow these enterprises to implement PDM functions without the need to predetermine the metadata structures.
- The investigation of the feasibility of using a comparison between metadata describing the state of the system at any instant with metadata describing a pre-planned list of design documents, for the purpose of managing workflow.
- The investigation of the feasibility of using visualisation of the metadata to aid management control (including PDM functions) of a product development process in SMEs.

These aims were accomplished by:

- Developing a new computer based method that automatically extracts types of metadata from the operating system of the computing environment to describe the state of the system at any instant.
- Developing a new computer based method that compares the state of the system at any instant with metadata describing a pre-planned list of design documents, for the purpose of managing workflow.
- Developing a new computer based method and tool to visualise the metadata captured from the operating system of the computing environment, to control a product development process in SMEs.

These activities are presented in Chapter Four. In that Chapter, the identified classes of data associated with the product development process are used to underpin the development of data management functions suitable for SMEs. The method that I developed, involving the

identification and automatic capture of product development process metadata and subsequent workflow management by comparison between predetermined and descriptive metadata is then presented. A platform to implement the method in a computer-based environment is then described.

As implementation involved detailed monitoring of the activities of employees in a computing environment; which could be construed as an invasion of their privacy; it was considered necessary to get their agreement on ethical grounds. The implementation of the monitoring software required a specification of a communication protocol. These technical and ethical considerations involved in the implementation of the method in a SME, are discussed in Chapter Five. The results obtained from an implementation of the method in a New Zealand SME are then presented in a novel, easily interpreted, graphical form. The feasibility of utilising these tools and methods for providing functions for data management are then considered.

Conclusions and recommendations for future work are presented in Chapter Six.

Chapter 1. New product development in New Zealand

The outcomes and conclusions of this thesis are intended to assist and increase the competitiveness and rapidity of product development by New Zealand Small and Medium Enterprises (SMEs). This chapter discusses the findings from a survey of product development practices in New Zealand's discrete product manufacturing industry that were used to identify the direction of the research in this thesis.

1.1 Introduction

Enterprises that can design, manufacture and position new products in the marketplace ahead of their competition gain considerable competitive advantage and hence, a greater probability of survival (Liu and Xu, 2001, pp. 252). Therefore, the tools and methodologies used by enterprises to manufacture products rapidly are of great importance. The introduction of new ways to support the design and manufacture of products is a critical research area.

In order to develop tools to improve new product development it is necessary to have knowledge of the recipients, in this case, New Zealand enterprises developing new products. Specifically of interest: Who are these enterprises? What are they doing? Where are they doing it? and most importantly, How are they doing it?

Public and private enterprises and institutions have been conducting research into the nature of New Zealand businesses for many years (see, for example, the Ministry for Economic Development (MED) (Manatu Ohanga, 2005), Manufacturers Associations (CMA, 2005) and Tertiary Institutions (Britton, 1978)). However, with regard to investigation of the tools and methodologies used for product development, conclusions from recent research into New Zealand design and manufacture practices are required. Recent research of this type is required for a number of reasons:

- **Obsolescence:** Technological and sociological changes since the advent of computers has rendered most historical data relating to the use of tools and methods in the product development process obsolete.
- **Intent and content:** most extant research data available regarding NZ enterprises (e.g. Gearing Up (Knuckey, Leung-Wai *et al*, 1999) and Firm Foundations (Knuckey,

Johnston *et al*, 2002)) concentrate on *what* activities an enterprise was performing rather than *how* the activities were performed. That is, such research focussed on studying New Zealand business practices and performances as opposed to the usage of tools and methodologies to achieve these outcomes.

- **Comparison:** Finally, extant data concerning the area of study has not previously been compared with similar data available offshore.

During 1998-2000, the use of design tools and methodologies for rapid product development was investigated (Shaw *et al*, 1999, Whybrew *et al*, 2001) and compared with a similar study undertaken in the United Kingdom (Araujo, Benedetto-Neto *et al*, 1996). This research was performed as part of a Public Good Science Fund (PGSF) research programme entitled “Rapid Product Development for World Class Manufacturing”. The New Zealand survey, in addition to providing data for comparison with the United Kingdom, also sought to provide data concerning activities such as the selection of products for development, organisational structures for design, design strategies and procedures, and the use of information technologies for new product development.

As this thesis is concerned with the management of product data, only those results pertinent to the identification and use of paper and electronic data within the surveyed enterprises are discussed. Further reading regarding the survey and other outcomes detailed above which describe the new product development practices of New Zealand enterprises can be found in the associated Technical Report (Shaw *et al*, 1999) (Appendix A) and in a paper presented to the International Conference on Engineering Design during 2001 (Whybrew *et al*, 2001).

1.2 New Zealand Enterprises that Develop Products

The popular view of New Zealand industry is that it is able to compete internationally in niche markets because it is innovative, with the ability to quickly introduce new products with production runs that are small by world standards (Whybrew *et al*, 2001). Certainly, data are available pertaining to the makeup of New Zealand businesses (Manatu Ohanga, 2003), however this type of data had not hitherto been related to the application of tools and methodologies for new product development, nor to the information technologies used for these purposes.

Findings from a survey (Shaw *et al*, 1999, Whybrew *et al*, 2001) are discussed in this section as they provides recent data on the design tools and methodologies that are used by New Zealand enterprises in product development processes. Furthermore, the report detailed information pertaining to the computer-based implementation of these tools and methodologies as well as the methods used to manage the generated data.

1.3 Findings

Unless otherwise stated all facts and figures reported in Sections 1.3 through 1.7 have been taken from Technical Report 58 (Shaw *et al*, 1999) and the paper “Use of Design Tools and Methodologies for Rapid Product Development in the New Zealand Manufacturing Industry (Whybrew *et al*, 2001).

1.3.1 Enterprise Characteristics

New Zealand Ministry of Economic Development figures from 2002 indicate that 70% of enterprises in the manufacturing sector employ 19 or fewer full time equivalent staff; thus categorising them as micro, small or medium sized enterprises (Manatu Ohanga, 2003). This classification would see 43% of the enterprises surveyed in the report labelled as SMEs, suggesting that the sample group was over-represented by a higher proportion of “larger” New Zealand enterprises. Interestingly, the European Union definition of a SME (EU, 2003) would see 86% of the survey respondents classified as SMEs. Regardless of these classifications, it is clear that New Zealand enterprises are small by global standards.

Despite being small by world standards, 43% of the enterprises surveyed exported more than 50% of their output. Not only were enterprises shipping products globally, in addition the products themselves had a high New Zealand Intellectual Property (IP) content: 81% of the enterprises surveyed performed design activities for products that were partly or wholly to be manufactured by their own organization. Four significant aspects with relevance to the product development process and the environment in which these activities occurred were identified by the survey:

Sub-contracting

The use of subcontractors to support the product development process by the sample group was extensive: Eighty five percent of the enterprises subcontracted at least one design related task and 64% at least two tasks. Tool design and manufacture were the most frequently subcontracted activities.

Alliances

Many enterprises had formalised their relationships with suppliers of goods or services: 50% of enterprises in the survey indicated that they had formed an alliance. Of these:

- 30% had “formal” procedures detailing how the alliance is controlled
- 35% had monitoring and enforcement plans
- 46% had established formal software and communications systems
- 80% had more than one alliance partner

Design Staff

The number of design staff an enterprise involved in product and/or tooling design activities was small: a majority (82%) of the enterprises surveyed had 6 or fewer personnel involved.

To summarise: New Zealand enterprises are small by world standards; the teams created for the development of new products consist of small numbers of personnel. The development of new products in New Zealand is a task that frequently crosses organisational boundaries.

1.4 Design Tools

The report compared a list of design tools and methods used by New Zealand enterprises with a similar study conducted in the United Kingdom. In New Zealand the most popular tools were:

- Brainstorming
- Design review meetings

- Product Design Specifications
- Benchmarking of competitor products
- Design mock-ups

It is significant that the tools that New Zealand enterprises found to be of most benefit are those related to the review and communication of information within design phases. Compared with the 1996 United Kingdom study, New Zealand enterprises appeared to make far less use of formal design tools and methodologies. The survey states that, on average, there is 25% greater use of these tools and methods by United Kingdom enterprises compared with New Zealand enterprises. Figure 1 compares the tool use by the surveyed New Zealand enterprises with the use by United Kingdom enterprises.

1.5 Software in the Design Process

The survey also reported data relating to the use of software to support the product development process.

1.5.1 CAD and other computer based design tools

The use of some form of computer-aided design (CAD) and/or analysis software in the product development process by the sampled enterprises was significant: 86% of respondents were using these types of software. Of the CAD users, 65% indicated they were using solid or feature based solid modelling CAD packages. Almost 30% of respondents had two or more design software platforms in operation. In addition to computer based CAD software, many enterprises employed computer based versions of the surveyed design tools.

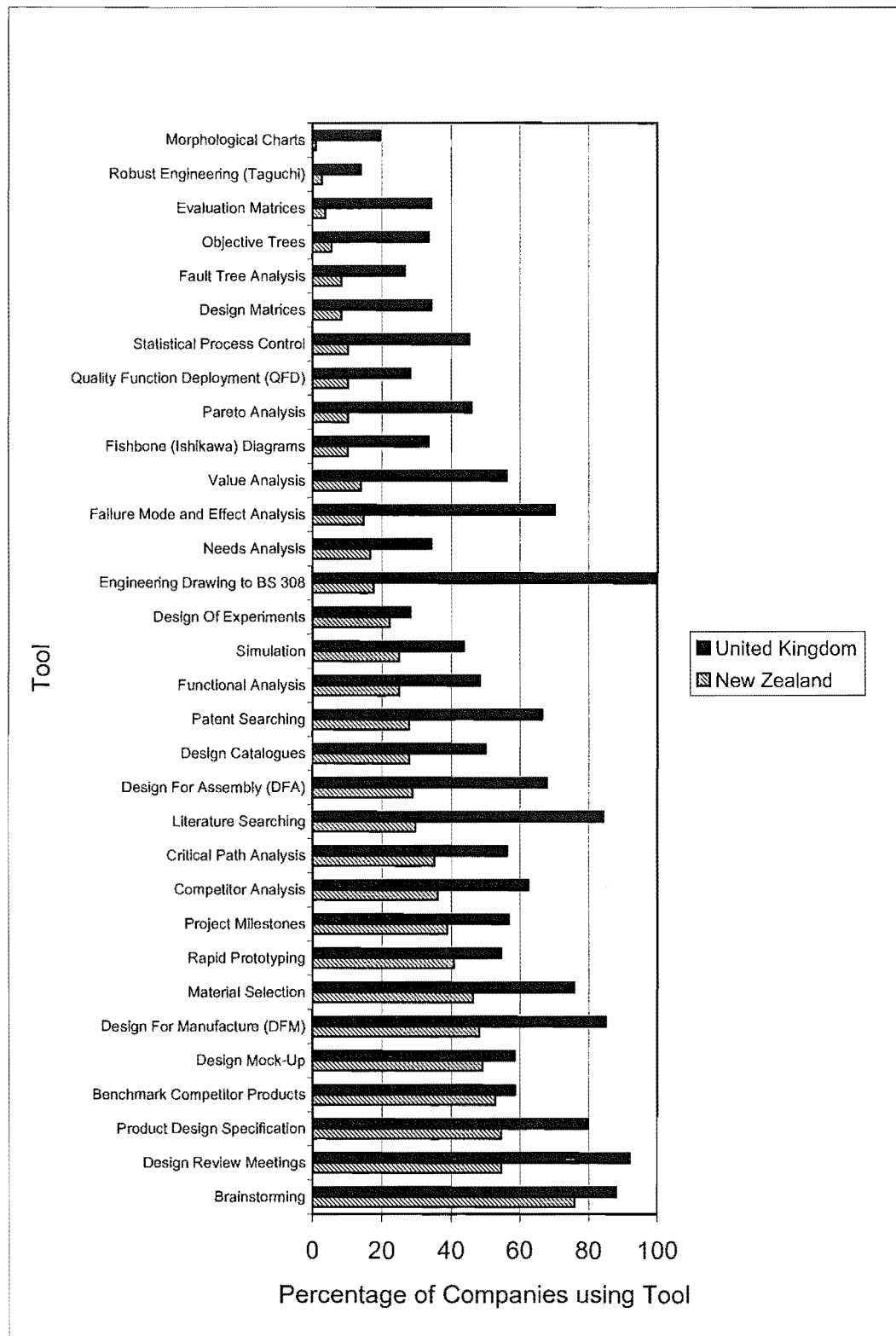


Figure 1. Comparison of Tool Use

1.5.2 Transfer and access to Information

The use of software by the surveyed enterprises for the communication of data relating to the product development process was high. More than 80% of enterprises reported the use of email to share product data information as part of their design process. Figure 2 details the methods of data transfer used by the surveyed enterprises.

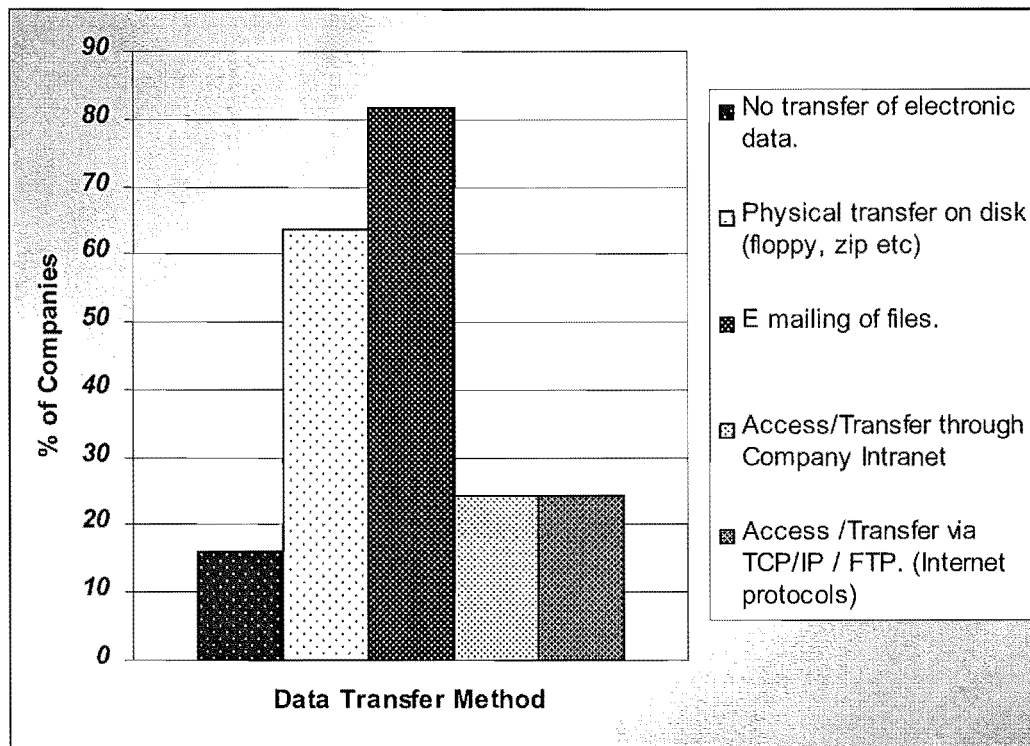


Figure 2. Method for Transfer of Data

In addition, the enterprises were using the Internet as a tool for product development activities in other ways. Examples included; the analysis of competitor's products, services and prices, searching for suppliers, provision of customer information and as a method of contact. Computers were also extensively used for the management of information databases. Figure 3 depicts the use of information databases and the percentage of enterprises that used paper or electronic based methodologies for these purposes.

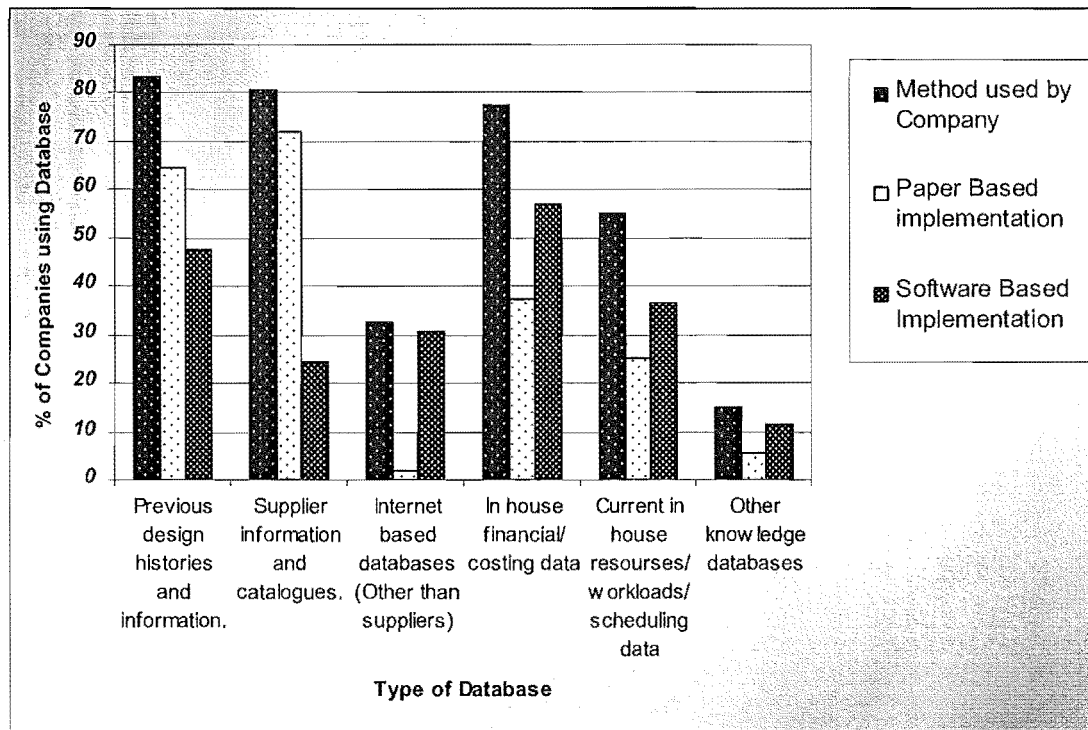


Figure 3. Use of Information Databases

In summary: The surveyed New Zealand enterprises used computer-based technologies for all phases and activities of a product development process. The author suggests that the volume of data created during the product development process can only increase as enterprises embrace newer information technologies within the workplace.

1.6 Management of Computer-based data

The survey responses discussed in the previous section indicate the extensive use of computer based applications to support the product development processes of New Zealand enterprises. With the use of all these applications, large amounts of data are being created and communicated between participants to support phases of the design process. It is known that the effective control of data (and therefore, information) can lead to a reduction in product introduction lead-times and consequently time to market (Garner, 1991, pp.15 Lemke, 2004, Obank, Leaney *et al*, 1995, Urban, Ayyaswamy *et al*, 1999).

The storage of product data in the surveyed enterprises was found to be paper and electronic based, with a mixture of both methods being frequently used. Enterprises routinely had

management systems for CAD file databases, however the extension of these systems to include **all** product-related data was non-existent.

Informal communication with survey respondents indicated that they recognised that a method of organising these files needed to be addressed, but that few enterprises had procedures for identification, storage and amendment for all types of data associated with a project. Many respondents acknowledged that they had problems finding product data files in the absence of key personnel. Data stored was *application specific* and *product specific* but more likely to be stored by *employee specific protocols*. Furthermore, anecdotal evidence suggested that the management of data was regarded as “paperwork” (administrative tasks) and thus was viewed negatively by participants; enterprises found problems ensuring such tasks were completed.

The use of some form of Product Data Management (PDM) software to control and access product data was limited to very few (10 %) of the enterprises; this data was more likely to control specific types of files (e.g. CAD Files) rather than *all* electronic data associated with the new product development process. Furthermore, this data was managed at specific points of the product development process. Where applications were used, enterprises appeared to have moved away from the in-house programming of applications (popular in the heyday of enterprise mainframe computers), to the purchase of vendor software. This commercial-off-the-shelf (COTS) software fell into two categories: purchased, then tailored for enterprise use by software vendors or purchased and used as-is by the enterprise. Smaller enterprises tended to use the second method.

There was little evidence found of the integration of application data used in the new product development process. The use of Microsoft products e.g. MS Office was wide-spread and afforded integration within some environments, but many enterprises used CAD, CAM, CAE, Enterprise Resource Planning (ERP), financial, project planning, electronic communication and supplier databases that were unable to integrate the data created.

Most enterprises recognised that both the control and integration of data was a problem that would grow as the use of software applications increased. Further insight into this problem was gained during a review of the design and development PDM requirements of Tait Electronics Ltd, Christchurch during 2003 (Shaw, 2003).

These reasons included:

- Reluctance to accept the structures and rules imposed by PDM system software
- The high cost required to implement PDM*
- Enterprise resources required to implement PDM
- Enterprise resources required to operate and maintain PDM
- Existing enterprise management and software structures.

* By way of example, a PDM system manufactured by Parametric Technology Corporation (PTC) has an average price per seat of USD \$1,495(Cohn, 2005), this is excluding implementation and ongoing costs and is despite the fact that the price per seat has fallen steadily since the time of the study.

In summary: Given the increasing use and storage of electronic data, the survey found very little use of Product Data Management, or similar software, for the control of data created during product development activities. Where computer based systems did exist they were oriented to the control of particular types of data; no examples were found that integrated and managed the entire set of data created by a new product development process. Users required any solutions to be cheap, and have minimal setup, application and operation resource requirements; qualities not found in currently available software products.

1.7 Summary

Data are created at all stages and phases of a new product development process. At the time of the survey electronic data was found to be created in all activities associated with the product development process. Current trends would indicate that the volume and type of data will increase in the 21st century as more and more applications become computer based. In New Zealand, this data is transferred to the participants in the product development process, both internal and external to the enterprise. The management of data is an essential component of success in the new product development arena; yet the survey suggested that there is a low uptake of technologies to manage the data that New Zealand enterprises create during a product development process.

Current offerings by software vendors are inadequate for New Zealand enterprise needs: enterprises require new tools and methodologies to manage the data they are creating in ever increasing amounts; these tools must be cheap, easy to implement, operate, maintain and fit within existing organisational and software structures.

Chapter 2. Literature Review

The survey reported in Chapter One looked at New Zealand enterprises and indicated the widespread adoption of computer-based tools and methodologies in the product development process. However, the low use of PDM systems by these enterprises suggests an opportunity for the development of tools and methodologies to assist the management of data. This chapter will report on the review of the themes of the literature search related to PDM and their application in SMEs. They were:

- the development of typologies for computer based product data management systems,
- benefits and difficulties associated with the implementation of such systems; both in general, and in SME environments,
- the methods by which people, enterprises and product development processes classified and use data and
- the methods used to identify the relationships between types of data.

A bibliography with suggested further reading around these themes is contained in Appendix Two.

2.1 Introduction

The communication of beliefs is used by enterprises to integrate the participants' conceptual spaces in a product design process. Paper, and increasingly, electronic media may be used by the participants to record and communicate their beliefs about the set of functional and structural properties of a design and the courses of action to realise and support those properties. To discuss these topics the concepts involved have been developed and presented to the reader. A glossary is contained in Appendix Three; it has been developed to attach meaning to the particular words used to describe the concepts presented in this thesis.

With respect to a product development process, the creation and communication of data between participating roles is paramount to the realisation of the product. If this creation and transfer of data is performed in an optimal manner, the product development process time may be reduced and strategic, tactical and operational benefits could be gained by an enterprise. The need for an enterprise to minimise product development time is an integral

part of the many strategies necessary to compete successfully in the 21st century marketplace and many enterprises seek ways to reduce this time-to-market (Wheelwright and Clark, 1993), (Smith and Reinertsen, 1995), (Morelli, Eppinger *et al*, 1995), (Eppinger, Krishnan *et al*, 1997).

Data relating to a product development process are most commonly recorded by enterprises in *documents* (Helms, 2002, pp.3). It is these documents that are created, amended and transmitted throughout an enterprise, and from which information is subsequently inferred to support the product development process.

Although the document is the current format for the encapsulation of recorded data, this state of affairs may not last. PDM developments in the last five years have seen systems emerge that manage discrete collections of data independent of a traditional document. The collections of discrete data are then assembled by software into the digital documents required for particular users by means of sophisticated IT applications. Thus, PDM software is gaining the ability to manage and communicate smaller amounts of discrete data throughout an enterprise. Regardless of this increasing micro-management of electronic data, the underlying concepts and functions used by current systems can still be utilised for this purpose.

Metadata and information inferred from metadata are used to assist these activities. The metadata is embedded in and/or associated with a document. The metadata enables individuals to infer information that relates to the document and/or software to perform programmed actions determined by the metadata present. By way of example, an engineering drawing frequently contains a Title Bar recording metadata such as; Drawing Title, Author, Date etc. This metadata may also be recorded separately, for example, in a database. The decision behind the location of the metadata relates to the *purpose* for which it is to be used. Depending on the format, both human beings *and* a set of computer based instructions are capable of processing metadata.

2.1.1 A short history of Product Data Management

This thesis is concerned with the data created by the product development process. Product data management (PDM) systems traditionally manage data solely related to the product *definition*. However, it can be argued that other data created and communicated by an enterprise supports the development of a product definition; and that the management of data

from these functions (e.g. marketing, finance, human resources etc.) is critical to the development of the product. Indeed, the years 2000-2005 have seen a trend towards the management of an expanded range of inter-organisational data with the increased adoption of so called “supply chain management” (Harland, 1996) techniques; at the same time, the functions associated with what were originally PDM systems, have evolved into Product Lifecycle Management (PLM) systems.

From paper-based methodologies, the management of enterprise data relating to the product definition has changed greatly with the widespread introduction of computer based information technologies (IT). Both hardware and software utilised for these tasks have evolved in parallel with the introduction of new technologies. Prior to the advent of so-called PDM systems, early Engineering Document Management (EDM) systems were utilised to manage documents within an enterprise.

The period 1980-1990 saw the introduction and widespread use of Computer Aided Engineering (CAE) tools (Bozdoc, 2000); these tools generated increasing volumes of Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) digital data. It was not until the late 1980's however, that the subject of computerised management of this engineering data began to be addressed; in 1987 the American Society of Mechanical Engineers (ASME) inaugurated an Engineering Database Program which included goals associated with the promotion, dissemination and discussion of engineering database management. By 1988 the term PDM (introduced by the consultancy group CIMdata Inc.) was being used to describe systems to manage engineering data (Johnson, 1988). From this time until the mid 1990's commercial PDM systems became more readily available and the functions associated with these systems were more fully refined. The penetration of such systems in the marketplace was, however, low: Carroll presents figures from Cimdata that suggests the market was worth only US\$100 million in 1990 (Carroll, 2000).

The CIMdata PDM Buyers guide of 1992 (Miller, MacKrell *et al*, 1992) defines the requirements of a PDM system during this period to be associated with: managing a vault of product data, automation of workflow processes, management of product structures, program/project management and the classification coding and retrieval of data.

The period 1990-2000 saw software developers and vendors rapidly developing solutions for PDM using information technologies. By the turn of the century, it was reported that the market for PDM software and services was worth approximately US\$2500 million with at least 74 different vendors offering solutions (Carroll, 2000).

2.1.2 PDM Definition

Identifying *what* functions a PDM system must perform to be called a PDM system is by no means an easy task. This situation is highlighted by Helms who noted at least as many as six different terms for systems offering data management functions for documents containing product definition data (Helms, 2002, pp.13). Examples given included: Technical Information Management (TIM), Engineering Document Management (EDM), Product Information Management (PIM), Engineering Data Management (EDM) and Collaborative PDM (cPDM).

Furthermore, Helms saw that the management of data as an internal enterprise process was shifting to management of data between enterprises; i.e. data managed throughout the so called “supply chain” of enterprises that constitute the participants delivering and supporting a product in the marketplace. Consequently, he defined PDM as:

“PDM is the discipline of making the right product and process related data available and accessible to the right parties at the right time in the product lifecycle in order to support all business processes that create and/or use this data.” (Helms, 2002, pp.13).

This definition draws attention to the fact that PDM is not exclusively a piece of software but a discipline “...a company can for example manage document versions without using a PDM system.” (Helms, 2002, pp.13). However, the software based relational databases utilised to store and manage product data and metadata add capability to the systems that would otherwise be inaccessible; for example, search and replacement functions based on an objects’ attributes and properties. The additional capability to use PDM objects to interact with other pieces of software and to exchange data, make computer-based PDM systems very attractive. (Caveat; of course, these systems actually have to be implemented in an enterprise to gain benefits and this is not always a trivial exercise; see Teschler (Teschler, 1997), and CADCAMNET (CADCAMNET, 2002), for example).

In 2004, the latest definition describes these product definition management activities as “Product Lifecycle Management” or PLM. A description given by CIMdata is:

- A strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information.
- Supporting the extended enterprise (customers, design and supply partners, etc.).
- Spanning from concept to end of life of a product or plant.
- Integrating people, processes, business systems, and information (CIMdata, 2004b).

A second description of PLM, given by the PDM Information Company (PDMIC) describes PLM as:

“Product Lifecycle Management - This offshoot of PDM really focuses on process automation and uses workflow tools to handle part and assembly definition and change processing over all the phases of use; early experimentation, product development, manufacturing, and field support.”(Schoenherr, 2005).

Comparison of the two PLM descriptions with Helms’ definition of three years earlier shows no discernable difference in core meaning (to this author); it represents an extension of the definition given by Helms, with more emphasis on the inclusion of technologies to enable collaboration and exchange of data over inter-organisational networks throughout all phases of the product development process.

2.1.3 PDM functions

Helms compared the different typologies of PDM systems (Helms, 2002, pp.14) (Helms, 2000) and found overlap in the functions offered by PDM systems. He prepared a list containing PDM system functions that were identified by more than one author. This list of functions is reproduced below:

- Vault Management
- Document Management

- Change Management
- Configuration Management
- Workflow/Process Management
- Product Structure Management
- Retrieval/Access Management

Helms noted that the typologies given were arbitrary and that the reviewed authors (with the exception of his colleague at the Eindhoven University of Technology, Pierre Breuls) did not discuss how they arrived at their typologies. Recent publications continue this trend, e.g. Mesihovic *et al* in their “State of the PDM use in Industry.” (Mesihovic, Malmqvist *et al*, 2004, pp.395). Breuls however, defined his typology on the basis of the “business objects” and “information”¹ that were required to be managed by the PDM to provide the necessary information required by participants (Helms, 2002, pp.14). Breuls and Helms defined their typology in terms of objects (abstractions of real world entities or concepts), in order to facilitate the Object-Oriented Representation (Meyer, 1998) of the concepts in the relational database software that underpins computer based PDM systems.

Furthermore, the product definition data that is managed by these systems is a representation of the definition at *frozen points in the design process*. It is a culmination of a set of activities that have occurred in the design process; that is, since the previous saved snapshot. The definition is frozen at particular points and then this data, in the form of documents, is passed as messages to participants to inform them of the product definition and therefore to assist them in their role in the product development process. Helms considered using PDM systems

¹ *Nota bene*: The terms data and information are defined in Appendix Three. Understanding these concepts, and the nature of the relationship between the two, is necessary in order to consider their management; unfortunately, this distinction between the two is frequently overlooked by both researchers and providers of PDM solutions. Many authors, Helms and Breuls included, suggest information is contained within a document (“For example, a drawing is a document that can contain information about a product” (Helms, 2002, pp.15)); it is this lack of understanding about the relationship between data and information that sees data labelled as information and vice-versa. A good example, shown above, indicates that a PDM and a PIM perform the same functions.

to control the release of partial information in order to facilitate concurrent engineering within an enterprise (Helms, 2002). However, this partial information was frozen in a similar manner which enabled it to be managed by the PDM schema. This current methodology means that, depending on the temporal gap between the points at which product definition data are saved, considerable data and information relating to the processes involved may be lost to an enterprise using such systems.

2.1.4 PDM function Model

Lacking a definitive typology, Helms developed a PDM function model for use within a RapidPDM project (Helms, 2000) and based it on the work of Breuls (Breuls and in Korbijn, 1999 (in Dutch)). As discussed above, they based their function model on the type of business *objects* and type of *information* that they considered needed to be managed by the PDM. Breuls distinguished four types of objects about which information should be stored:

- Activities
- Products
- Resources
- Documents

As well as three types of information concerning those objects:

- Content information
- Relationship information
- Lifecycle information

Breuls then considered that the functions of a PDM system were to manage:

- *Object Repository Maintenance*: The collection of activities whose aim is the optimal storage, retrieval and maintenance of data. This may be stored in electronic format as well as on conventional paper or microfilm archives.
- *Object Structure Maintenance*: The collection of activities aimed at managing relationships between objects. It involves managing object structures such as a product structure or a work breakdown structure.

- *Object Lifecycle Management*: The collection of activities aimed at providing guidance and supporting creating, using, changing and removing objects from the viewpoint of managing related information flows. (Helms, 2002, pp.15).

Helms developed a PDM function matrix to explain his PDM function model; combining (on the vertical axis) the functions for managing different types of information and (on the horizontal axis in Table 1) the functions for managing different types of objects. He considered that resource management was more a function of project management than PDM and therefore combined Breuls' activity and resource objects into a process/project object. (Helms, 2002, pp.16).

Object Lifecycle Management	Document Lifecycle Management	Product Lifecycle Management	Process/Project Lifecycle Management
Object Structure Management	Document Structure Management	Product Structure Management	Process/Project Structure Management
Object Repository Management	Document Repository Management	Product Repository Management	Process/Project Repository Management
	Document Management	Product Management	Process/Project Management

Table 1. PDM Function Model

The nine functions of a PDM system as defined in the Function Model matrix are summarised as follows:

Document Repository Management: The functions required to; manage the vault containing the documents, identify and otherwise number documents, view and annotate documents; and scan and image documents.

Document Structure Management: The functions required to model and view the structure of the document sets and the relationships between them thus giving rise to the ability to assess change impact analysis.

Document Lifecycle Management: The functions required to control document versions; to identify the status of a document in its lifecycle (e.g. draft, released, obsolete); and to control their release to users. The status and version control of the lifecycle of document structures.

Product Repository Management: The functions required to identify, classify and catalogue the product.

Product Structure Management: The functions required to model the product structure and its configurations, to facilitate the viewing of the structure and links to calculations, and to investigate change impact analysis.

Product Lifecycle Management: The functions required to manage product versions, to identify their status and to control their release. To control the status and version of product configuration lifecycles.

Process/Project Structure Management: The functions required to identify and track processes associated with the product development process.

Process/Project Repository Management: The functions required to model organisational structures and work breakdown structures: and to facilitate the viewing and searching of these models.

Process/Project Lifecycle Management: The functions required to plan, track and manage workflow processes.

The differentiation between PDM and PLM occurs when the management of data is extended from organisational processes to processes employed by groups of enterprises throughout the product's lifecycle. Whereas a collaborative function was not considered to be a core function by Helms (but was nevertheless offered as a function by some PDM vendors), it becomes very important over distributed collaborative networks. Thus, the core functions of a PLM system are extended from those of a PDM system to allow participants to collaboratively interact with the data over distributed networks. As a major provider of PLM systems notes in a sales brochure:

“In product development today the practice of exchanging information means that massive data files must be shared more frequently, in a wider variety of forms, among more globally dispersed team members.”(PTC, 2003).

These collaboration functions can be defined as:

Collaboration Structure management: The functions required to identify and track collaborative activities associated with the product development process.

Collaboration Repository management: The modelling of collaborative structures and the facility to view and search these models.

Collaboration Lifecycle management: The functions required to plan, track and manage collaborative processes.

Such functions can be represented in a fourth column, “Collaboration Management”, in Table 1.

2.2 Implementation of PDM systems

Harris (Harris, 1996) reviewed case studies of the implementation of PDM systems into large enterprises from a number of sources and identified several barriers to implementation. These barriers included: users of the system and their culture, lack of awareness of technology, confusion of the differences between PDM, EDM and other systems, concerns with integration of data between other systems, data migration problems and the significant costs involved in both purchasing and maintaining a system.

A survey of six Swedish enterprises concluded that a PDM solution could not be bought as an off-the-shelf product and that “implementing an enterprise-wide system for information and process management requires substantial investments, mainly as own labor and external consulting resources” (Sellgren and Hakelius, 1996). Similar problems with the implementation of PDM systems are reported by; Malmqvist (Malmqvist and Pikosz, 1996), and Sackett (Sackett and Bryan, 1998). As well as these barriers and the requirement to commit large amounts of resources to implement the systems, Teschler notes that poor implementation of PDM systems can potentially cut enterprise revenue (Teschler, 1997).

CADCAMNET also identify other barriers to the implementation of PDM systems: volume (in large enterprises, the volume of relationships between data is typically much higher than the volume of data itself), relationship definitions, training, administration and time taken to access the data itself. They make specific mention of the impact of human factors on the use and implementation of PDM systems. (CADCAMNET, 2002). Siddiqui *et al* surveyed a range of engineering enterprises in differing industrial sectors and considered that PDM implementation problems related mostly to personnel issues, for example lack of management support, user acceptance and implementation issues (Siddiqui, Burns *et al*, 2004).

However, despite these barriers to implementation, benefits can accrue from the adoption of these systems. CADCAMNET, for example, reports success with an implementation of a PDM system in an enterprise with 2,200 employees and annual sales of more than USD\$500 million that took three years (CADCAMNET, 2004).

Literature on the implementation of PDM systems has, until recently concentrated on the adoption of such systems by large enterprises. It was not until around 2000, that their use of PDM systems within the context of the characteristics of SMEs started to be discussed (Abramovici and Gerhard, 2000, Caillaud and Passemard, 2001). Abramovici noted in 2002 that PLM technologies were primarily used in the automotive and aerospace industries; that is, in large enterprises that have long product lifecycles. He observed (he did not say where this figure came from) that 53% of small enterprises were still showing no activity in the field of PDM. (Abramovici and Sieg, 2002). A recent CIMdata positioning paper discusses PLM and PDM implementations and suggests that historically these solutions were practical, “primarily for large, distributed enterprises that had the extensive resources required to deploy and maintain them” (CIMdata, 2004a). The paper considers that mid sized enterprise (US\$100 million to \$1 billion in annual revenue) adoption of PLM will grow apace.

However, while these types of systems were gaining acceptance in the engineering sector and researchers contributed to the functions that constituted PDM systems, there was little research to investigate their structure and implementation within an enterprise itself. Harris (Harris, 1996) noted that, while significant bodies of research work could be associated with the enablers of PDM systems (e.g. methods for: activity, data, information and process modelling; database systems; configuration management, exchange methodologies, etc), little work was published on how these enablers related to an overall business strategy for

manufacturing enterprises. That is, there were “significant bodies of work on the individual elements that constitute the enabling mechanisms for implementing a PDM strategy, but little that links these together cohesively” (Harris, 1996, pp. 216).

Harris identified these enabling methods, standards and technologies of PDM to be:

- Activity and Process modelling
- Data and Information modelling
- Models and technologies for product data exchange, sharing and languages
- Database systems
- Classification and coding
- Configuration management

(Harris, 1996, pp. 215)

In addition to a scarcity of research in the PDM field relating the individual fields in a cohesive manner, entire domains of research associated with these concepts appear to be disconnected. For example, a similar set of functions and enabling technologies are utilised by the software product development community yet there is very little crossover between the two disciplines (Estublier, Favre *et al*, 1998).

The bibliography in Appendix Two contains selected background readings that discuss these enabling technologies. It will be appreciated that the six enabling technologies detailed above cover a considerable number of research areas and thus the bibliography is only recommended as a starting point for the Reader.

Harris’ review detailed a summary of emerging research questions that he considered important in relation to the subject of product data management strategy (Harris, 1996, pp. 215). He saw that the lack of investigation into enabling technologies and their relationship to the strategies of the enterprises that would employ them was of concern and that these areas needed to be addressed.

Harris raised some other interesting questions with respect to PDM systems. In reviewing this field Harris concluded that most of the PDM research is focussed on the constituent emergent technologies and found that “there is little that attempts to develop a rigorous understanding

of the relative importance of each of these enablers within the larger context”(Harris, 1996, pp. 215). Unfortunately, Harris’ concerns appear to be well founded; recent publications relating to PDM systems continue to be focussed on the constituent technologies: see for example; the papers “State of the Art in PDM/PLM and CAx” (Weber C, Werner H *et al*, 2003) and “State of the PDM use in Industry” (Mesihovic *et al*, 2004).

It is clear that specific technologies enable functions of a PDM system. However; what is not so clear is the rationale behind the inclusion of particular functions as part of a PDM system. CIMdata, who coined the term PDM, identified functions of such systems but did not determine a typology; it was not until 2002 that the first typologies were addressed by PDM researchers (Helms, 2002). This research into the development of a definition and typology for PDM systems is discussed in section 2.3 below.

Similarly, product “data” is managed by these technologies, yet there is no clear definition by PDM researchers of the types and classes of data that such systems manage (see for example: (Do, I.J. *et al*, 2002, Hameri and Nihtilä, 1998, Helms, 2002, Obank *et al*, 1995, Riitahuhta, Salminen *et al*, 2002)). Yet, in other research fields, data is clearly recognised as belonging to particular categories: for example, Morelli *et al* in their research using Design Structure Matrices to predict technical communications identified three different types of data used by an enterprise (Morelli *et al*, 1995).

Although there is substantial research into individual functions, enabling methods, standards and technologies of PDM, (see bibliography), there is little research investigating whether particular types or classes of enterprise have an impact on the requirements of functions and enablers of PDM systems. It is known that the size and type of an enterprise influences the implementation of such systems (see Section 2.3 below), but another question may need to be asked: does the size and type of an enterprise have a bearing on the functions and enablers of PDM that are required?

While the size and type of an enterprise may have a bearing on the functions and enablers of introduced PDM systems, another factor is not widely discussed in the literature: PDM systems are used by people. That is, the systems manage the data to support the endeavours of human beings. Do all individuals infer the same information from the same piece of data? If not (and this is the belief of the author), then the mechanisms by which individuals produce

and communicate data may well need to be accounted for in the development of PDM functions and enabling technologies. Following this theme, this literature review, in the field of PDM, failed to find any research that considered the mechanisms by which the *users* of the data interacted with data managed by PDM systems.

In order to provide the context lacking in the current literature and explain the identification of, and interactions between, types and classes of data, enterprises and people that use PDM systems, this thesis develops, in Chapter Three, a comprehensive model for this purpose. This fundamental model is required as, to date, PDM research has not considered the contextual effect that types and classes of data, enterprises, processes and people have on the functions and technologies developed for PDM.

2.3 Organisational Models

It is stated above that the aim of Chapter Three is to develop a conceptual model of product design and manufacture processes that create digital data during a product development process. To achieve this aim the model must be capable of representing the people, organisations and product development processes that classify, integrate and use data. Such a model must consider therefore, the:

- Essential elements that comprise an organisation
- Interaction of roles to achieve integration of organisational elements
- Types and classes of data communicated by the roles to achieve integration of organisational elements
- Processes employed by the organisation that utilise data

To the author's knowledge, there is no current model available to provide the necessary basis to represent these concepts. To develop a model that accounts for these relationships I integrated the models of Ackoff and Emery (Ackoff and Emery, 1972) (communications between people), Beer (Beer, 1981) (the structure of organisations), Hales (Hales, 1986) (product development process phases), and Garner (Garner, 1991) (organisational integration). The development and validation of the model is explained in Chapter Three.

2.4 Workflow

A comprehensive review of workflow literature is beyond the scope of this thesis. The intent of this section is to identify shortcomings of workflow systems that preclude their use for the management of product development process data by SMEs. Further reading around this theme is, however, contained in Appendix Two.

Current PDM systems have, as identified above, a workflow function to assist the management of the flow of data. Enterprise processes require the movement of data both within and external to an enterprise; *workflow* is defined as “systems that help organisations to specify, execute, monitor and coordinate the flow of work cases within a distributed office environment (Bull Corporation, 1992). The ability to manage process workflows using information technologies has only become readily available in the last decade (van der Aalst, *et al*, 2003).

The basis of current workflow methods is the task-oriented approach (van der Aalst *et al*, 2003); activities in a process are decomposed into a series of tasks and the routing of data between these tasks automated. These formalised tasks are pre-determined before the tasks are initiated (Perez and Rojas, 2000). That is, they are “normative in the sense that they state what “should” be done rather than describing the actual process” (van der Aalst *et al*, 2003).

The pre-determination of workflow to manage business processes has weaknesses (Agostini and de Michelis, 2000, van der Aalst *et al*, 2003) that render this approach inadequate for the management of the majority of product development activities. The major drawback is an inability to pre-determine all product development activities (and hence, tasks) at the outset of the project. The designer of a product development process workflow model is thus unable to construct a robust model accurately describing the routing of work. Consequently, only the simpler product development processes, where the workflow is invariable (e.g. Engineering Change Orders (ECO's)) are modelled.

In addition to the above identified weaknesses of workflow systems there is some evidence (Whybrew *et al*, 2001) that SMEs utilise a different method to manage product data. That is, the SMEs use a goal-based approach to manage workflow in preference to the task-based management of data used by existing PDM workflow systems. Rather than specifying the

tasks associated with activities, SMEs specify the outcomes of the activities, namely specific documents that have to be completed. In effect, the structure of a PDM system is used to control users through interaction in a prescriptive manner that is determined by the system designers. This type of rigorous approach may not be appropriate for smaller enterprises, as their small size and the ability of participants to interact allows a more flexible approach to product development. Many enterprises in the survey said a major strategy was “*working closely together*” and one inference from this statement is that the strategy allowed participants to exchange data and information more readily and in an unconstrained manner. That is, due to the ability to work closely, the enterprises regarded a lack of prescription as an asset that gave them an advantage in product development. The provision of PDM for SMEs must therefore necessarily account for these two factors if workflow functions are to be considered.

2.5 Summary

This Chapter has reviewed the development of typologies for computer based product data management systems, benefits and difficulties associated with the implementation of such systems (both in general, and in SME environments), and the methods by which people, enterprises and product development processes classify and use data in PDM systems. The key concepts involved in this thesis have been developed and a glossary appended (see Appendix Three) to attach meaning to the particular words used to describe the concepts presented in Appendix Three. A review of the history and application of methods to manage data associated with the product development process has been presented.

PDM systems are seen to be a collection of functions, enabled by emerging technologies that manage data across the phases of a product development and deployment process and, out of necessity, across organisational boundaries. The systems can be implemented in a number of ways and need not involve the use of so-called information technologies (IT). Although expensive in terms of resource requirements, when designed and implemented effectively these systems can improve product development processes by reducing time-to-market, improving quality and reducing costs.

However, the literature surveyed suggested that, while there was a wealth of research associated with enabling technologies for individual functions that comprise PDM systems,

there was a lack of research that places the PDM systems within wider contexts. It was concluded that little consideration had been given in the PDM research community to the relationship between classes of data, data users and enterprise structures on the development of the functions and emerging technologies for PDM systems.

It was also concluded that, in current PDM systems, metadata between the points in the process where the product definition data is frozen and where data is created, amended and passed between participants in the form of messages is unable to be captured by current systems. That is, current PDM systems do not manage the data between points where the product definition is frozen. This current methodology implies that, depending on the temporal gap between the points at which product definition data is saved, considerable data and information may be unavailable to an enterprise using such systems.

Implementations of PDM systems were found to be mostly the domain of larger enterprises; however, the growth for mid sized enterprises is predicted to increase. Although costly in terms of the resources required to implement these systems, they have been shown to provide benefits to the enterprises that employ them. The use of PDM by smaller enterprises is only recently becoming a topic for research. Research in this area will become important for a number of reasons:

- the majority of the world's enterprises are SMEs
- SMEs frequently form part of the supply chain of the larger enterprises.
- Benefits accrue from the use of PDM/PLM systems

It was further concluded that a specific function of PDM systems, workflow, lacked the ability to manage some processes associated with the development of products and that the underlying concepts used for this function by such systems may not be applicable to SMEs.

In Chapter Three this thesis develops a comprehensive conceptual model to provide context and explain the identification of, and interactions between, classes of data, roles, processes and organisations that use PDM systems. This fundamental model is required as, to date, PDM research has not considered the contextual effect that classes of data, enterprises and people have on the functions and technologies developed for PDM. To research this area a

conceptual model must first be developed. The developed model will be applicable to small, medium and large enterprises.

Chapter 3. Development of research model to identify data classes and interactions in the product development process

This chapter develops a research model to investigate the data created in the generation of the documents traditionally managed by PDM systems. The model identifies the classes of data and the mechanisms behind the interactions that occur during a product development process. It is this model that, in Chapter Four, will be utilised to underpin the development of PDM functions to assist in the management and integration of the design data.

3.1 An introduction to key authors

This thesis will draw on the concepts, theories and models developed by Beer, Ackoff and Emery, McCallion, Britton and Garner, in the field of systems theory.

(Anthony) Stafford Beer was a key figure in Operational Research (OR) during the second half of the 20th century. His work concerned the way that decisions made by complex social systems could best be achieved. Building on the foundations of cybernetics laid down by Norbert Wiener (Wiener, 1948, Wiener, 1961), Ross Ashby (Ashby, 1952, Ashby, 1964) and Warren McCulloch (McCulloch, 1970, New York Academy of Sciences. and McCulloch, 1961) he developed a systems approach to the holistic management of enterprises. His first book, *Cybernetics and Management* was published in 1959 (Beer, 1959) and his research into neurophysiological models led to the development of the Viable Systems Model (VSM) detailed in the *Brain of the Firm* (Beer, 1981) and his associated books: *The Heart of the Enterprise* (Beer, 1979) and *Diagnosing the System for Organizations* (Beer, 1985). The VSM set down the “necessary and sufficient criteria for an organisation to be integrated and viable.” (Garner, 1991, pp.39).

Beer’s model, based on biological concepts, viewed the organisation as a whole with its members passively acting under the direction of particular systems within the organisation. This assumption of passive action by the parts (individuals) has become increasingly untenable; the increased generation and distribution of wealth and knowledge in the last hundred years has seen massive changes to individual and social behaviour of organisational

members (Toffler, 1990), (Ackoff, 1979), (Gharajedaghi, 1999). There are, however, extreme cases of societal control where loyalty, conformity and commitment are paramount, e.g. paternalistic (Gharajedaghi, 1999, pp.20) or dictatorial organisations, in which the model may yet be applicable.

To account for the complexities associated with the individual interactions between the parts (individuals) of an organisation, the model developed by Russell Ackoff and Fred Emery in their book *On Purposeful Systems* (Ackoff and Emery, 1972), based in psychology, (and the philosophy of work by E.A. Singer Jnr. (Singer, 1936, Singer, 1948, Singer and Churchman, 1959) and C. West Churchman (Churchman, 1957, Churchman, 1968, Churchman and Ratoosh, 1959, Singer and Churchman, 1959)) can be utilised.

Ackoff and Emery explain that a purposeful system is “one that can change its goals in constant environmental conditions; it selects goals as well as the means by which to pursue them. It thus displays will. Human beings are the most familiar examples of such systems.” (Ackoff and Emery, 1972, pp.31). Their model described a system with the ability to both select the goals to be achieved and the methods to achieve the goals within a given environment. In creating their model, Ackoff and Emery also spent considerable time developing the definitions that were to be used.

In Christchurch, New Zealand, Harry McCallion utilised the Beer and the Ackoff and Emery frameworks to direct both research and teaching in the topic of Engineering Organisations. Two of his postgraduate students used these models and theories extensively in their Doctoral Theses. Graeme Britton investigated the use of the models for the purposes of modelling the activities of technical manpower (Britton, 1978). Andrew Garner used the models of both Beer and of Ackoff and Emery and the work of Britton and McCallion (McCallion and Britton, 1991) to develop a purposeful design model consisting of 10 interacting design roles in order to allow a diverse set of beliefs to be incorporated into the production of an integrated design hypothesis.

McCallion, Britton and Garner saw that both the Beer and the Ackoff and Emery frameworks represented integrated open systems capable of choice and that they were *fundamentally the same*. Garner, in his thesis, gave arguments to support this premise while also considering the

two important differences between the two; namely, the difference in structure and originating foundations (Garner, 1991, pp.56-58).

Garner used both models, showed how they complemented each other and how they could be utilised for the purpose of organisational integration. He used Ackoff and Emery's model to describe how the interactions between organisational roles influenced a designer's belief in the development of a design hypothesis; i.e. a model of the purposeful *parts* of an organisation. The interactions were structured to ensure that semantic and pragmatic facets of communication were correct by identifying both how the designer's beliefs are formed and the method by which they are validated. Beer's VSM was employed to ensure that the system was sustainable in larger, changing environments, over a period of time. Therefore, Beer's VSM is a model of the *whole* of the organisation.

The reader has been given a brief introduction to the work of Beer, Ackoff and Emery, McCallion, Britton and Garner, as the work of these authors has contributed to the development of the definitions discussed below. A more comprehensive review of the work of these authors is discussed below as a prelude to the models developed in this thesis.

3.2 Systems

An organisation that develops new products is a system. The nature of a system is such that:

1. A system is a whole that is defined by its function(s) in one or more containing systems.
2. Every system contains at least two essential parts and these must satisfy three conditions:
 - "Every essential part of a system can affect its behaviour or properties.
 - The way an essential part affects the properties or behaviour of the whole depends on the state or activity of at least one other part of the system.

- Groups of essential parts, subsystems, also can affect the behaviour and properties of the whole system and none has an independent effect on it.” (Ackoff, 1999).

Ackoff and Gharajedaghi classify an organisation as a *social* system (Ackoff and Gharajedaghi, 1996, Ackoff and Gharajedaghi, 2003). In an organisation both the *whole* and the *parts* of a social system display choice. Furthermore, the process of developing new products by an organisation can also be viewed as a system. As Garner notes:

“The process of design(ing) is a system... A design represent(s) a system of beliefs, beliefs about what is important for that product to satisfy the needs of the environment and the abilities of the firm” (Garner, 1991, pp.37-38).

For an organisation to be successful at product development a high degree of organisational integration is required (Garner, 1991, pp.15). Failure to do so heightens the risk of poor product quality, missed deadlines, lost opportunity and products unsuitable for the marketplace. Organisational integration necessitates a clear understanding of both the essential elements that comprise an organisation (the *whole*) and the purposeful relationships that exist between functions (the *parts*). The successful incorporation of all the requirements of the organisation and its parts that are involved in product development necessitates the integration of participants’ conceptual spaces (Britton and Whybrew, 1991). Verbal communication is insufficient; misunderstanding will occur if the syntactics, semantics and pragmatics of the communication are not correct or, as Ashby and Beer indicate that it (verbal communication) does not ensure requisite variety (Ashby, 1964) (Beer, 1981).

Mechanisms for the recording and transmission of beliefs are methods an organisation uses to integrate participants’ conceptual spaces in a product design process. Paper, and increasingly, electronic media are used by the participants for recording their beliefs about the set of functional and structural properties of a design, the courses of action to realise and support those properties, as well as the passing of messages that encapsulate these beliefs.

In addition to integrating the beliefs of the participants during the development of the design hypothesis, the participants themselves perform tasks or activities that assist in the development of their own beliefs about the organisations’ required set of functional and

structural properties and the course of action required to achieve those properties. These activities and the data that supports their beliefs may also be recorded and are often passed to other players in the form of messages in order to elucidate their beliefs.

Finally, at the end of particular stages in the product development process, the design hypothesis² is frozen and the set of functional and structural properties are confirmed. The integrated set of functional and structural properties and a probable course of action to realise those properties are then communicated to manufacturing and other functions of an organisation. A PDM system supports these activities by storing representations of the products functional and structural properties and probable courses of action. Additionally, functions manage the transfer of these documents between participants in the process. However, as we have seen, the data generated in the process of creating the product definition data (which is stored by the PDM system) is not itself managed.

This thesis concerns the development of a new tool for the computer based management of the data that is generated during the development of the product definition data. It is suggested that this tool could be used to improve the integration of the design hypothesis and the management of the organisational functions of the system. In order to investigate this theory a model of the classes of data created in an integrated product development process must be created.

Choice of model is important: Ackoff and Gharajedaghi argue that when models of one type are applied to systems of a different type then this mismatch can result in system failures when the models are used (Ackoff and Gharajedaghi, 2003).

² Product development techniques such as concurrent engineering require the release of preliminary versions of the design hypothesis before it is complete; authors (Eppinger, et al., 1997, Hanssen, 2000, Helms, 2002.) distinguish between “preliminary information” and “complete information” and its provision in the product development process. That is, the set of functional and structural properties before the design is frozen are “preliminary” and later, “complete”. They describe the benefits of releasing information in preliminary form to other organisational functions before the design is frozen. It is known that the effective release of this preliminary data can lead to improvements in the product development process (Hameri and Nihtilä, 1998, Helms, 2002, Obank, et al., 1995.).

To this end, Andrew Garner's Purposeful Design Model (Garner, 1991) (based on the Viable System Model (VSM) as developed by Stafford Beer (Beer, 1981) and the work of Russell Ackoff and Fred Emery on Purposeful Systems (Ackoff and Emery, 1972)) is further developed to model the mechanism of record and message creation during product development activities. This social system model is then encapsulated as a process model using Dallas' (Dallas, 1998) modification of Hales' (Hales, 1986) engineering design phases.

The aim of this chapter is to create a fundamental model to establish the relationships between organisational functions involved in the product development process and thereby to identify the role and classes of data in the integration of the beliefs of participants.

3.3 Background to the Model

Britton and McCallion described the essential roles for the successful performance of a team whose task involved significant "intellectual" effort and showed how it could be applied to a design team. (McCallion and Britton, 1991). Support for this model was forthcoming by comparison to that of Brooks – the Chief Programmer Team Model (Brooks, 1975) which was used to develop computer software. To integrate and coordinate multiple teams within large organisations Britton and McCallion employed a recursive organisational structure (Ackoff, 1981, Beer, 1979, Beer, 1981) which used vertical and horizontal cross-linking of particular roles within the organisational structure.

This model was modified and extended by Garner (Garner, 1991); A Purposeful Design Model, consisting of 11 interacting roles was developed to allow a diverse set of beliefs to be incorporated into an integrated solution. Garner used Ackoff and Emery's model of a Purposeful System or Individual (Ackoff and Emery, 1972) to describe how the interactions between roles influenced a designer's belief in the development of a design hypothesis. Therefore, it is a model of the purposeful *parts* of an organisation. The interactions were structured to ensure that semantic and pragmatic facets of communication were correct by identifying both how the designers beliefs are formed and the method by which they are validated. The recursive properties of a second model, Beer's VSM, were employed to ensure that the system was sustainable in larger, changing environments, over a period of time. Therefore, it is a model of the *whole* of an organisation. Garner considered that:

“To produce an effective design of an artefact a designer must have four integratable models, one for each of the needs of the client, the capabilities of the organisation, the functioning of the artefact in its environments, and the environmental values of society in relation to its eventual disposal” (Garner, 1991, pp.58).

The Purposeful Design Model was seen as a tool that enabled a designer to develop these models. Garner viewed product development as a System Four activity in Beer’s Viable System Model “product development is carried out to ensure a future for the organisation and is therefore one of the system four activities” (Garner, 1991, pp.59). The reader is at this point directed towards Garner’s thesis “The development of a model for organisational integration through integrated hypothesis development” (Garner, 1991). The thesis also contains an introduction to the theories of Beer and Ackoff and Emery and a more comprehensive description by Britton and McCallion (a reprint of Britton’s course notes for an undergraduate engineering paper entitled *Engineering Organisations*).

Garner’s thesis identified the interactions between roles in terms of purposeful systems and then utilised the recursive properties of Beer’s VSM to provide a control mechanism for closure of the design hypothesis when instability developed between the roles. The model detailed in the following sections of this chapter extends the Purposeful Design Model to consider the creation and communication of data within the product development process and the organisational system that supports that process. The model considers the creation and communication of data from the viewpoint of organisational integration.

A development of Garner’s model is necessary to identify data that is used to integrate conceptual spaces for four reasons:

1. Garner’s model details only the types of interactions that occur between roles in the hypothesis development process. That is, there is no consideration given to *what form* these interactions take; this thesis investigates the form of these interactions. Specifically, a model of the role of data in these interactions will be developed and used to explain how the data supports organisational integration.
2. Garner’s model details specific interactions between each of the necessary roles to produce an integrated design hypothesis. It will be shown that a general model can be

created that is applicable to all roles and that this model can be used to identify the role of data in organisational integration.

3. The current role relationships discussed in Garner's model can be used to identify the product definition data that is subsequently controlled by PDM systems. However, the model cannot identify the creation and exchange of data that occurs before product definition data are released to the organisation.
4. While Garner's model details specific interactions between each of the necessary roles to integrate the design hypothesis, the *process* by which these interactions occur and the activities that occur are not defined. The interactions and activities need to be associated with identified phases of a product development process. These interactions and activities do not occur simultaneously (but may be commenced concurrently), e.g. task clarification must be commenced before concepts are determined. To this end, Dallas's (Dallas, 1998) modification of Pahl and Beitz's (Pahl and Beitz, 1988) and Hales' (Hales, 1986) representation of the phases of the product development process will be utilised to order the interactions required for the integration of the design hypothesis and identify the activities that occur.

This thesis considers product development as a tactical activity performed as a System One activity (with reference to Beer's VSM). That is, the product development that occurs is undertaken as an activity for customers. Garner's Purposeful Design Model is applied in the context of this System One activity; the model is then extended to consider the creation and communication of the data generated in these activities as part of the product development process. It will be seen that this data may be used as the basis of a model for managing the integration and co-ordination of the design activities. Subsequent chapters of this thesis will use the model to develop and evaluate tools to assist the integration and co-ordination of the design process.

3.4 Activities and outputs

Activities and outputs are associated with specific phases of the design process by Hales and by Pahl and Beitz; the authors identify activities and outputs that participants complete as part of a process – of course, any list is not exhaustive: Hales identified thirteen more activities

than Pahl and Beitz during his quantitative analysis of the design process (Hales, 1993, pp.42). Furthermore, it is not inconceivable that the widespread implementation of information technology (IT) in the product design and development processes will engender the use of as yet unidentified activities. It is these activities and outputs and the messages passed that create data. Furthermore, it is the data representing the culmination of these outputs and activities at specific points in the process that are managed by PDM systems.

Organisations frequently have a prescriptive list of documents that must be completed and that, upon their completion, indicate that a particular activity and output is complete; that is, they identify the types of data that are likely to be produced and recorded. For example; an enterprise may require a document called “proposal” to be produced at the completion of the proposal phase of the design process. Thus, enterprises may have a template of what they consider is a “document set” to mark the completion of an entire process. At the outset, they may not know what the documents contain, nor who will create them, but it can be established which documents *should* exist at points throughout the process and also at the completion of the project. This fact can be used to create a template or model that specifies what documents must be created; furthermore these documents are associated with particular temporal points in the product development processes. That is, a *prescriptive* model of the recorded activities and outputs required during a design process can be determined (Shaw and Aitchison, 2003).

Not all documents that will be created during a process can be predicted; thus, at the completion of a process, the document model will comprise a prescriptive set (what will be produced) and a descriptive set (what was produced) of documents.

Regardless of the completeness of the document model at any stage of the process, the documents are created for the purposes of communication between roles; that is, they are messages containing product definition data. Current PDM systems manage only those documents which are judged essential for use by an organisation. Other documents, generated in the process of creating the product definition documents that will be controlled, are not managed.

Note that, in addition to communication between different roles, documents can be used to communicate with a future player in the same role. The model that follows will describe the

method by which data and metadata are created by activities that occur during the creation of documents that will contain the product definition data managed by PDM systems.

3.5 Interaction of Roles in the product development process

Ten interaction models were developed by Garner and their purpose was stated as: “Ackoff and Emery’s model of the purposeful individual or system behaviour is used to describe how each interaction influences the designer’s beliefs in developing his design hypothesis. The way in which certain interactions provide *information* to the designer, to develop his beliefs, ensures that the semantic and pragmatic aspects of the communication are correct”(Garner, 1991, pp.60) (my italics).

It is clear that Garner’s interaction models require the provision of information between roles in order to influence the beliefs and feelings of the participants. Information has already been shown to be inferred from data by a purposeful individual; therefore, the method of provision of data and the method by which the recipient receives it, are of importance if we are to attempt to model and manage data within the organisation.

There is more than one method by which data generated by the participant roles can be conveyed between the roles (e.g. verbal communication, hand signals, drawings). However, the most prevalent mechanism in current use is to record the data and/or metadata and incorporate it in a document, be it of paper or electronic media. These documents are then conveyed throughout the organisation and its environment and the information inferred by a purposeful individual is used for many applications.

It is this recorded data that is used to produce a change in beliefs and hence, outcomes, of a second purposeful individual. Additionally, both data and metadata must be translated into a language understandable to other groups and individuals in a manner that minimises the error in information inference. To record and translate data, a Documentor (one of Garner’s 10 roles) is required and the desired outcome is a document that records the data in a language suitable for communication to other individuals within the organisation or environment. Garner’s ten role interactions are used to develop a general case of the interactions between two roles. This general case models the requirements for pragmatic and semantic communication between all roles within the organisation or its environment.

3.5.1 Model of a purposeful individual or system

A diagrammatic model of a purposeful individual or system can be drawn as follows:

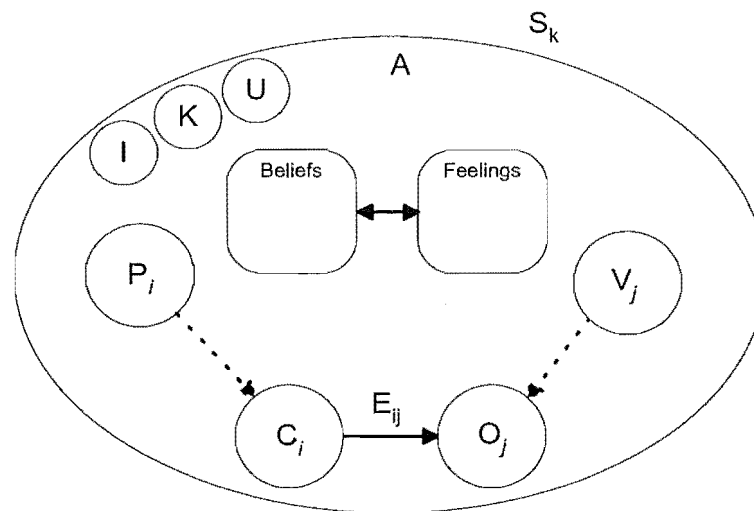


Figure 4. A Purposeful Individual

Where:	A:	is the purposeful individual or system
	S_k :	represents the state of the individual's particular area of interest (environment)
	V_j :	represents the probability of selecting a particular objective/outcome
	O_j :	is the objective/outcome
	P_i :	is the probability of selecting a particular course of action
	C_i :	represents the courses of action available to achieve the desired result
	E_{ij} :	is a measure of the persons efficiency in using C_i to achieve O_j
	I:	is the information that the person has to estimate his P_i 's
	U:	is the understanding that the individual has of the influence of S_k on the E_{ij} 's
	K:	is the knowledge the person has on how to execute the C_i 's and hence his E_{ij} 's
	Beliefs:	are the person's beliefs about the states and processes, past, present and future, relative to his situation.
	Feelings:	are the person's feelings relating to the degree of satisfaction he has or expects to have with regard to outcome or events produced by his actions or his environment.

This is a brief summary; see Ackoff and Emery (Ackoff and Emery, 1972) for an in depth description of these definitions.

When there is an intent by a purposeful individual to produce a behaviour in another purposeful individual, communication is required. A communication model will now be developed.

3.5.2 Communication Model

The choice of a person P to send a message to another person O, about a topic X, and the kind of message sent is dependent on the properties of both P and O. (Note that P and O may be the same person). Ackoff and Emery have determined that these activities are likely to be influenced by the following properties (Ackoff and Emery, 1972, pp.180-181):

1. p's beliefs about x: pUx
2. p's attitude towards x: pLx
3. p's belief about o: pUo , or how p believes o will respond to possible messages from p about x. In particular:
 - o's beliefs about x, oUx : $pU(oUx)$
 - o's attitude towards x, oLx : $pU(oLx)$
 - o's beliefs about p, oLp : $pU(oLp)$
 - o's attitude toward p, oLp : $pU(oLp)$
4. p's attitude toward o: pLo

A message or communication can result in changes to the receiver's probabilities of choice, efficiencies of courses of action and the relative value of possible outcomes. Ackoff and Emery (Ackoff and Emery, 1972, pp.144) define these outcomes as follows:

- Information: A communication that produces a change in any of the receiver's probabilities of choice informs him and hence transmits information.
- Instruction: A communication that produces a change in the efficiencies of any receiver's courses of action instructs him, and hence transmits instruction.
- Motivation: A communication that produces a change in any of the relative values the receiver places on possible outcomes of his choice motivates him, and hence transmits motivation.

Garner detailed each interaction required between all 10 participant roles in a Purposeful Design Model to ensure the integration of the design hypothesis. However, Garner discusses

the “conveyance of beliefs” and the “information provided” (Garner, 1991, pp.61-88) between the roles. The form of the communication was not discussed; the following communication model details the activities required by an individual to produce a behaviour in another purposeful individual. The model is not limited to the provision of information but also shows how instruction and motivation can be communicated. The model further shows that Garner’s individual interactions can be developed into a general model, regardless of role interactions; the interactions of which are of an iterative nature.

To select a method of communication, P must establish the beliefs and feelings of O towards P:

- P's beliefs and feelings about O are communicated to O
- O develops new beliefs about P (as a result of the communication of P's beliefs and feelings about O and O's own feelings about P)
- O's new feelings about P (as a result of O's new beliefs about P) and O's new beliefs about P are communicated to P
- P's develops new beliefs and feelings about O as a result of the communication of O's beliefs and feelings about P

P also needs to establish the beliefs and feelings of O towards X :

- P's beliefs and feelings about X are communicated to O.
- O develops new beliefs about X (as a result of the communication of P's beliefs and feelings about X and O's own feelings about X)
- O's new feelings about X (as a result of O's new beliefs about X) and O's new Beliefs about X are communicated to P
- P's develops new beliefs and feelings about X as a result of the communication of O's beliefs and feelings about X

P's new beliefs and feelings regarding O and X influence P's probability P_i of choosing a course of action C_i to communicate to O about X. P may elect to inform, motivate or instruct O and the outcome O_j will be a form of communication to achieve this.

- Inform: A change in O's P_i
- Instruct: A change in O's E_{ij}
- Motivate: A change in O's V_j

This is represented diagrammatically in Figure 5.

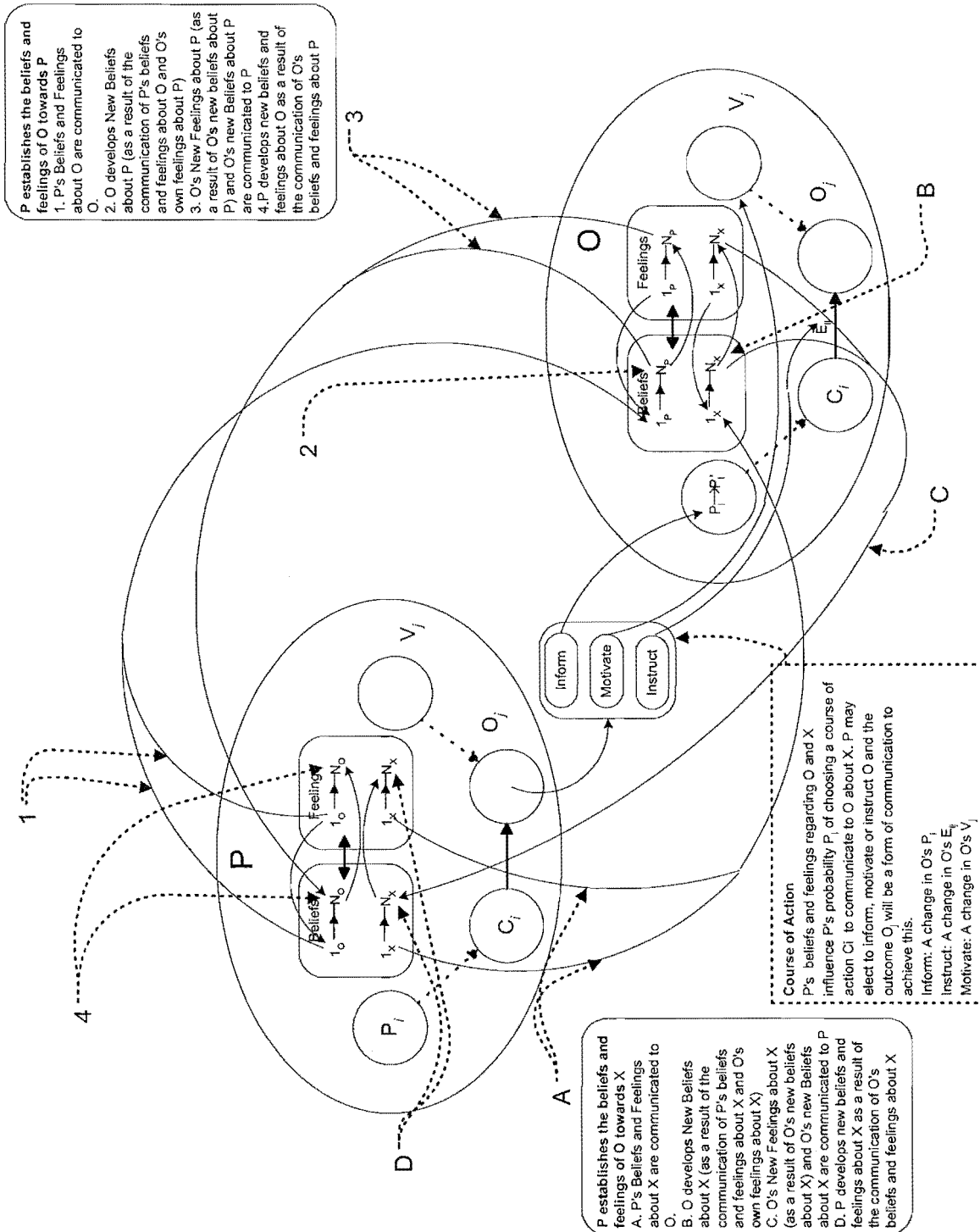


Figure 5. Communication Model

3.5.3 Documents as a message format

Having modelled the mechanism by which P determines a course of action to communicate with O about X, the form of communication can be addressed. This thesis is concerned with paper and electronic formats as mechanisms for the recording and transmission of this

message format as they are a method an organisation frequently uses to integrate participants' conceptual spaces in a product design process. Paper and increasingly, electronic mediums are used by the participants as a recorded method of informing, instructing and motivating role players in the process.

P records data about X and transmits it to O; metadata regarding the record is also frequently recorded. That is, in addition to data about X the subject, metadata may include the author, name of the record, location, document status etc. The metadata associated with the record may be imbedded in the record (both paper and electronic formats support this function) or held as a separate record. The metadata may be transmitted to O and/or other role players within the system. If P selects this form of communication to inform, instruct or motivate O about X he creates a paper or electronic document, it consists of two parts: data and metadata. When the recipient receives this data the following activities occur:

- Recipient (O) of Document acquires data and/or metadata
- New *Information* may be inferred from the data by O: This is dependent on a) O's beliefs about the data and b) the amount of syntactic, semantic and pragmatic noise contained in the message.
- O may also acquire new Knowledge, Understanding, Beliefs and Feelings as a result of receiving the data.
- This may result in the following changes to O:
 - O may be Informed: A change in O's P_i
 - O may be Instructed: A change in O's E_{ij}
 - O may be Motivated: A change in O's V_j

These activities are represented diagrammatically in Figure 6.

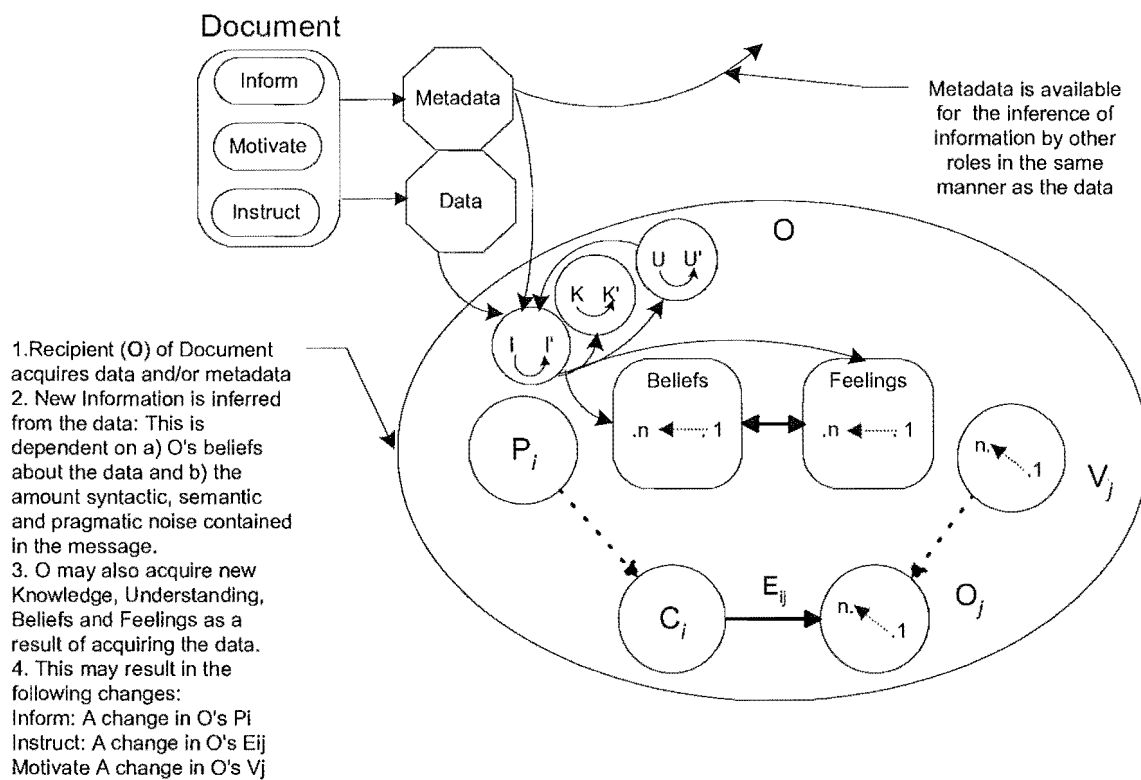


Figure 6. Data acquisition Model

3.5.4 Communication between Roles as parts of an Organisation

A general model of the communication between two roles has been established. From this a specific case model; a document as a message, has been developed. This model will now be applied to the interactions between roles as identified in Garner's Purposeful Design Model for the purposes of identifying data generated during a design process.

This Purposeful Design Model identified the 10 necessary role interactions that are necessary for the integration of the design hypothesis in the product development process. They are:

- Designer~Client Interaction
- Designer~Co-Designer Interaction
- Designer~Functional Expert Interaction
- Designer~Belief Expander Interaction
- Designer~Critic Interaction
- Designer~Sub-Designer Interaction

- Designer~Design Hypothesis Freezer Interaction
- Designer~Documentor Interaction
- Designer~Administrator Interaction
- Team Member Developer Interactions

These purposeful interactions between the roles (or parts of an organisation) need now to be shown in the context of an organisation. Garner grouped the role relationships into four categories and established links between the roles. See Figure 7, Below.

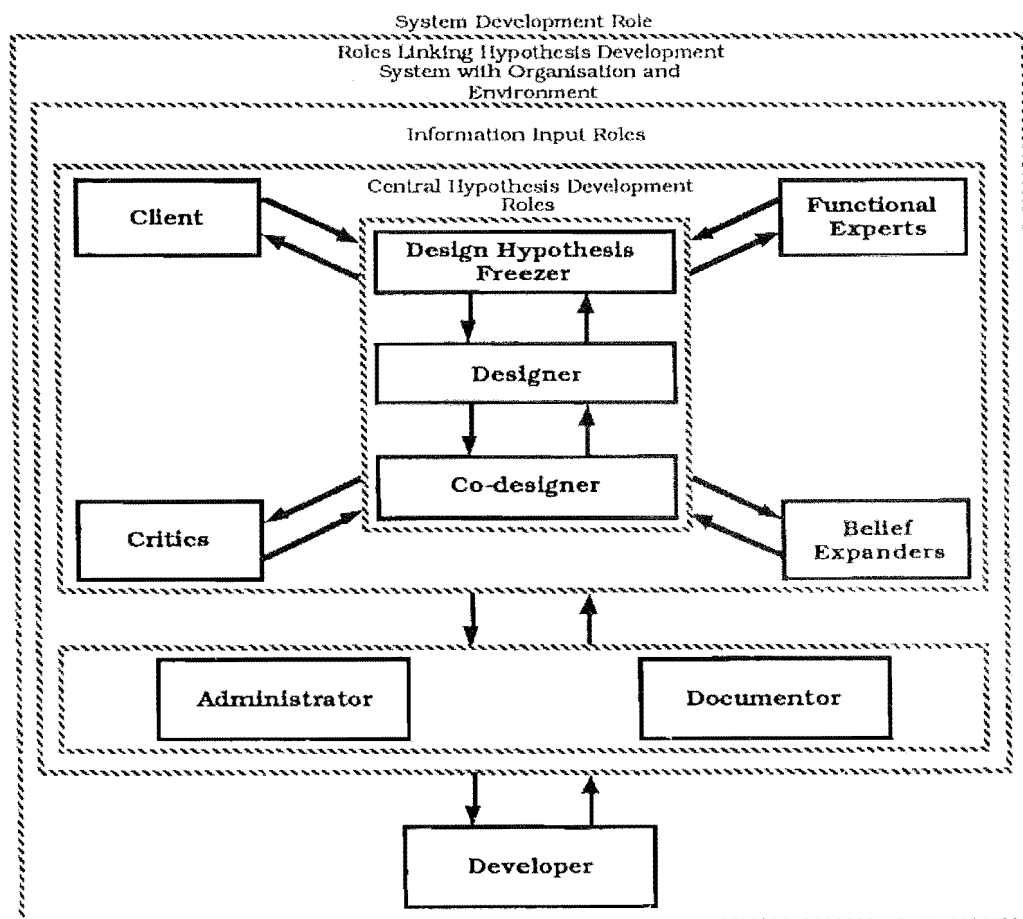


Figure 7. Role Relationships
(Copied from Garner, 1991, pp.90)

In Figure 7, it is the boundary between Garner's "Information input roles" and the "Roles linking Hypothesis development system with organisation and environment" at which a PDM system traditionally manages data. That is, the partial or full product definition formed by

Garner's "central hypothesis development roles" is translated and amplified by the documentor to be understandable by other groups; these documents then pass through the "Information input roles" to the wider organisation.

In Figure 7, Garner depicts the activities performed by the "central hypothesis development roles" as not having access to the Documentor role as part of their interactions: the model is *only complete* if the roles communicate without recourse to the creation of documents to exchange beliefs about the design hypothesis. If the roles participating in the "central hypothesis development roles" use documents to communicate then the role of a documentor *must be* included.

Thus, the role of Documentor must not only integrate the design definition documents with the wider organisation *but it must also* integrate the communication of documents within the "central hypothesis development roles". The communication model previously developed in 3.4.2 and 3.4.3 describes the mechanism by which communication of documents occurs within Garner's "central hypothesis development roles".

To summarise: Garner's Purposeful Design Model accurately describes the creation of the product definition data representing an integrated design hypothesis that is released to an organisation. It is this data that is traditionally managed by a PDM system. However, the interactions between participants when they communicate in order to integrate their design hypothesis beliefs frequently require the passing of messages; these messages are frequently documented. The communication model developed in 3.5.2 and 3.5.3 can be used to describe the activities that must occur for *each and every interaction* (depicted by arrows) in Figure 7 above, to ensure that a message is received and responded to. Furthermore, the model identifies and distinguishes between the data and metadata created by these interactions.

3.5.5 Communication between roles as parts of an organisation utilise a process

Each of Garner's Purposeful Design Model roles necessary to develop an integrated design hypothesis occurs as part of a process: a Product Development Process (PDP). These interactions are not simultaneous: different interactions occur at different stages of a PDP.

Various models of the design process have been utilised to describe design as a systematic process. Hales (Hales, 1993) used the model of Pahl and Beitz (Pahl and Beitz, 1988) for studying the engineering design process; he subsequently amended this model by adding an extra phase: *proposal*. However, as Dallas noted (Dallas, 1998, pp.25) both the Pahl and Beitz and Hales models cease at the completion of manufacturing information. Product development frequently extends to pre– production and for this reason the Dallas modified phases of the design process are used for this model. The phases are then be described as (Dallas, 1998, pp.26):

- Proposal: Through a proposal, the task is established. The output is a product proposal.
- Task Clarification: Through Task Clarification activities, the problem is defined. The output is a design specification.
- Conceptual Design: Through Conceptual Design activities solutions are generated, selected and evaluated. The output is a concept.
- Embodiment Design: Through Embodiment Design activities the concept is developed. The output is a final layout.
- Detail Design: Through Detail Design activities every component is fixed in shape and form. The output is manufacturing information.
- Pre-Production: Through Pre-Production activities, every component is proven. The output is a design of a manufacturable product.

A sixth phase was added to account for activities that occur after pre-production:

- Post-production: Through Post-Production activities, every component is used in its end environment. Data are returned to the design environment and the output is the potential re-design of a manufactured product.

This phase ties in with the PLM and the data that is generated and managed as a result of the final phases of the design's lifecycle. That is, the data that is available for feedback into a new product development process. For example, customer feedback data for iterative design, maintenance and service data as well as a host of other data.

Three key models have now been introduced:

- The Purposeful Design Model detailing necessary roles and interactions to ensure an integrated design hypothesis.
- The developed communication model detailing the mechanism of these interactions and the data and metadata created.
- The amended Dallas model describing the phases of the design process.

Together these models can be used to describe the creation and dissemination of all data created during a product development process. The combination of these models account for the purposeful nature of the individual within an organisation and the data that they produce. Stafford Beer's VSM will now be used to model the systems necessary to ensure these activities occur in a viable organisation.

Beer's VSM could not be used alone for the purposes of this thesis as he took the requirements for individual and organisational behaviour to be the same; as Ackoff notes: "the difficulties in implementing his model derive from the purposeful nature of the parts of the organisations" (Ackoff and Gharajedaghi, 2003, pp.6). However, it is proposed that all four models together in a metamodel can be used to describe the creation and use of data within a viable organisation.

A rendition of Beer's VSM is detailed in Figure 8. See Garner (Garner, 1991, pp.39-49) for an introduction to the model. Garner also includes, in an appendix to his thesis, a reproduction of a Non Technical Version of Stafford Beers Viable System Model by Britton and McCallion (Britton and McCallion, 1989) which is recommended to the reader. Beer's own books will further an understanding of the model (Beer, 1975, Beer, 1979, Beer, 1981). Briefly, the VSM comprises six subsystems and the environment in which they occur:

- System 1: Production Elements: Management, Production, Operations
- System 2: Coordination
- System 3: Operational Control
- System 3* Operation Monitor/Auditor
- System 4: Self Awareness
- System 5: Identity

A rendition of Beer's VSM is presented in Figure 8 (overleaf). The model comprises the five systems identified by Beer. The interactions between each of these sub-systems and the environments in which they function are developed. These subsystems are such that the model aims to specify the "minimum functional criteria by which a given organisation can be said to be of independence existence" (Espejo and Harnden, 1989). It is this model of the *whole* of the organisation, in which Garner's PDM roles (and whose purposeful interactions have now been modelled using Ackoff and Emery's purposeful system model) were considered. The resulting model accounts for the purposeful interactions between roles within a viable organisation that is conducting a product development process.

Roles are associated with different systems in Beer's VSM. For example, the role of designer is associated with System 1, the production elements, whereas the role of Proposal Freezer is associated with System 3, Operational Control. Note that an additional role, Marketing, has been added to the proposal phase in Figure 9 to reflect this function within a product development process. In a product development process the roles required to support different phases of the process change; as the organisation moves from phase to phase of a product development process roles are added or subtracted from the activities associated with the various systems during the phase.

However, we must consider the changing nature of an enterprise as it follows a plan or process to achieve its goals. Beer's VSM can be utilised to represent the roles involved and the interactions between roles at different phases of a process. Figures 9-15 depict Garner's 10 PDM role interactions utilising a model of Beer's VSM. The models are modified for each phase of a Dallas idealised product design process to show the changes in roles and interactions as an organisation moves through product development phases. That is, the phases of Proposal, Task Clarification, Conceptual Design, Embodiment Design, Detail Design, Pre and Post-Production.

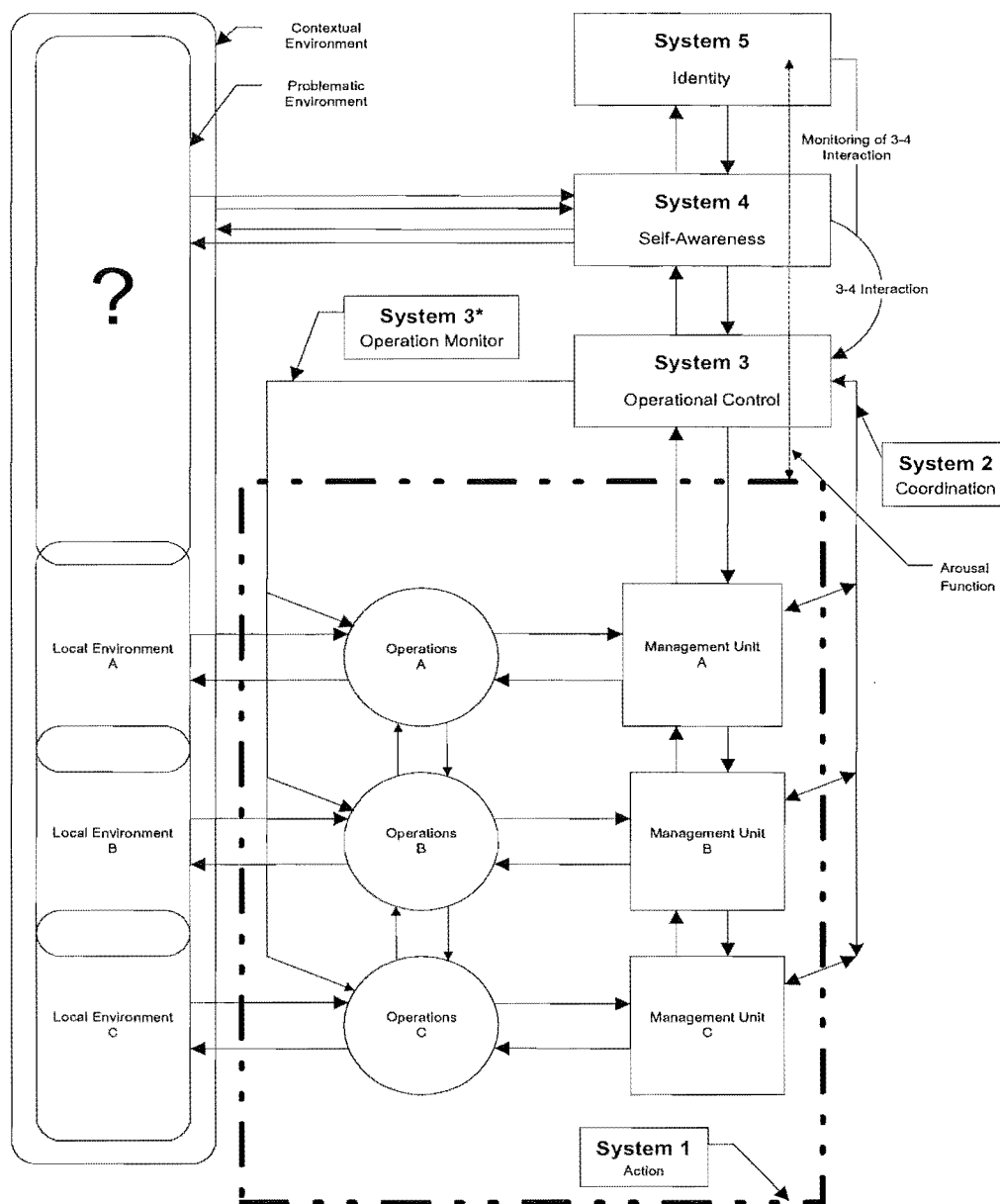
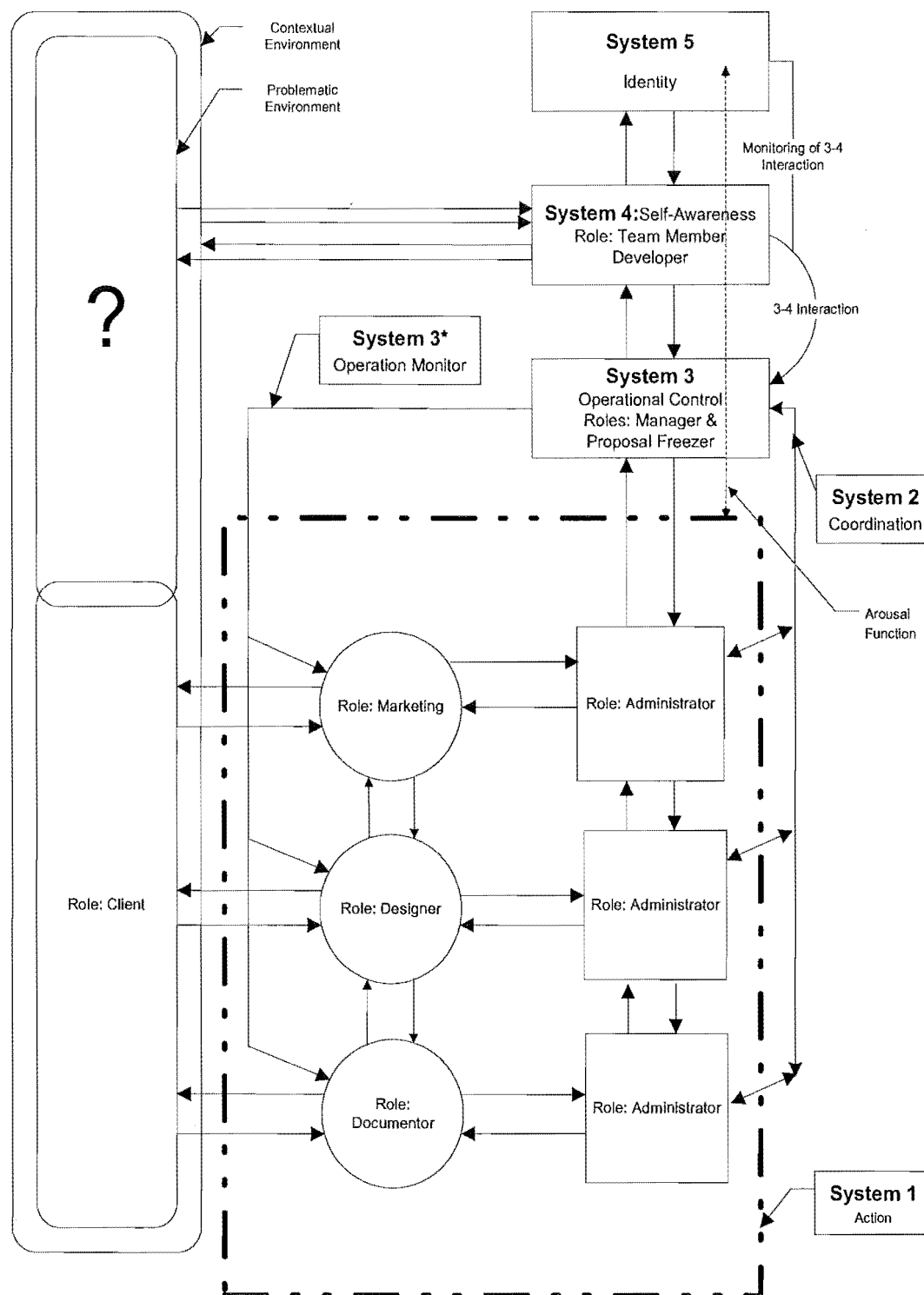


Figure 8. Beer's Viable System Model (After Beer, 1979)

The role of Documentor shown in Figures 9-15 is a role developed by Garner and represents the activity of readying the design definition for release to other functions within the organisation, at defined points in the process. Where arrows are depicted in Figures 9-15 they indicate interactions between roles, independent of a Documentor; the reader should note that the communication model developed previously describes the true nature of these interactions.



In Figure 9, the Proposal phase, a task is established; the documented output of this phase of the product development process is a product proposal. The roles required for this initial phase are identified and ascribed to Beer's subsystems. An operational marketing role is required to assist identification of a proposal; a proposal freezer role is required to freeze a proposal and stop further iterations of proposal development.

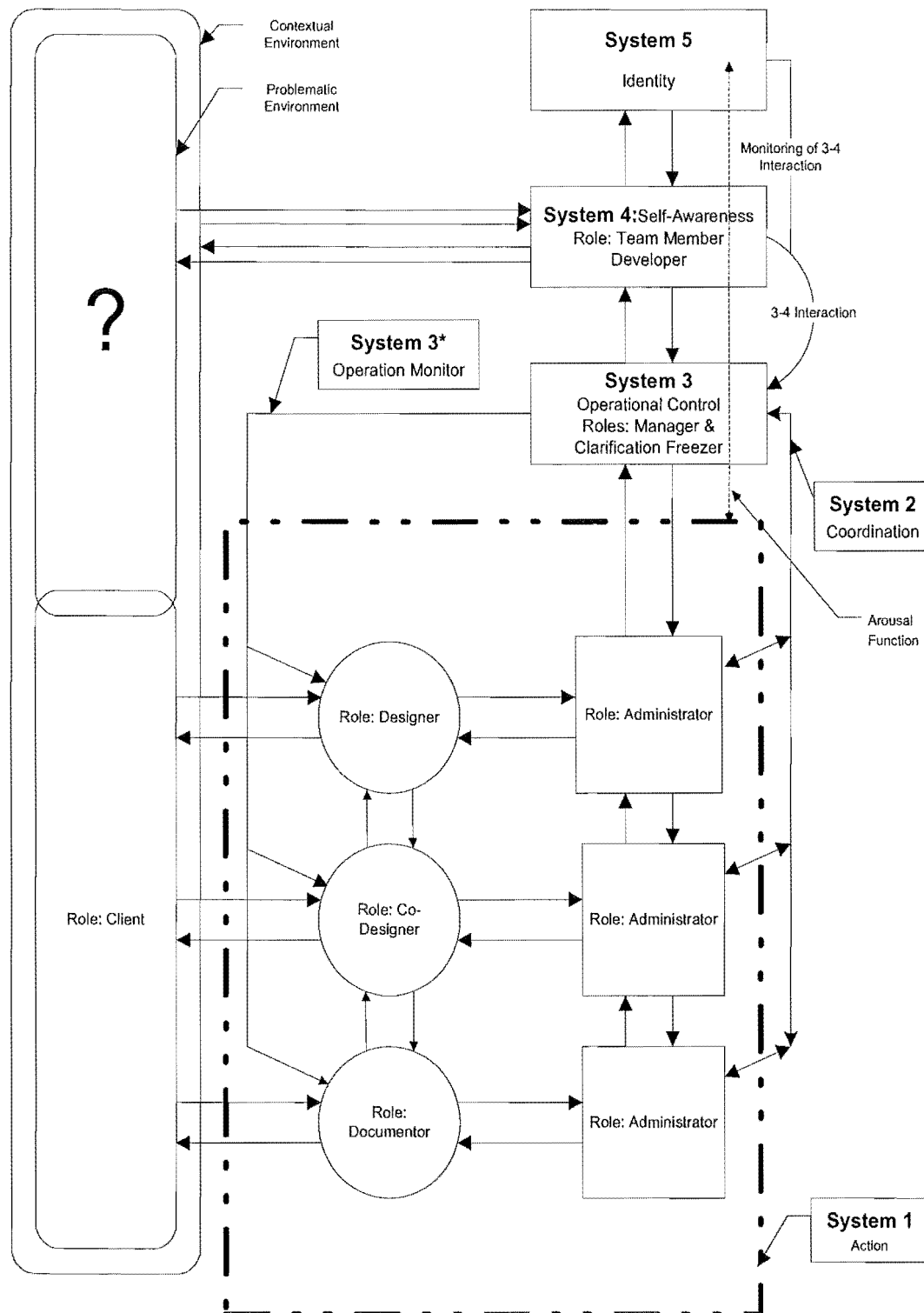


Figure 10. Task Clarification

In Figure 10, the Task Clarification phase, the problem is defined; the documented output of this phase is a design specification. Designing is now the main operations role, reflected by a new co-designer role. A new role, to freeze the design specification, is performed by System 3.

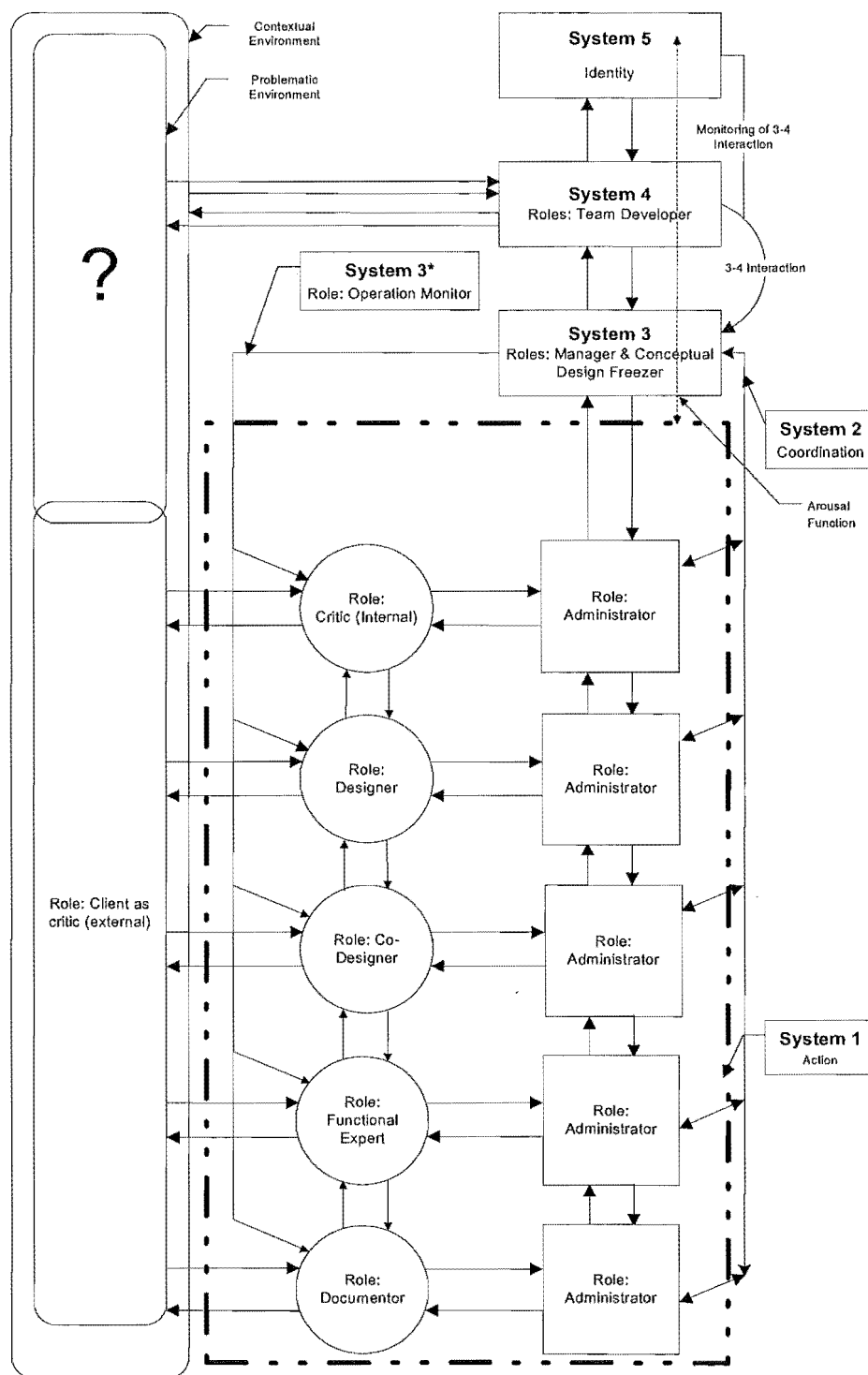


Figure 11. Conceptual Design

In Figure 11, the Conceptual Design phase, design solutions are generated, selected and evaluated; the documented output of this phase is a concept. The roles of functional experts and critics are required to develop the design; a conceptual design freezer role is required to freeze a concept and stop further iterations of concept development.

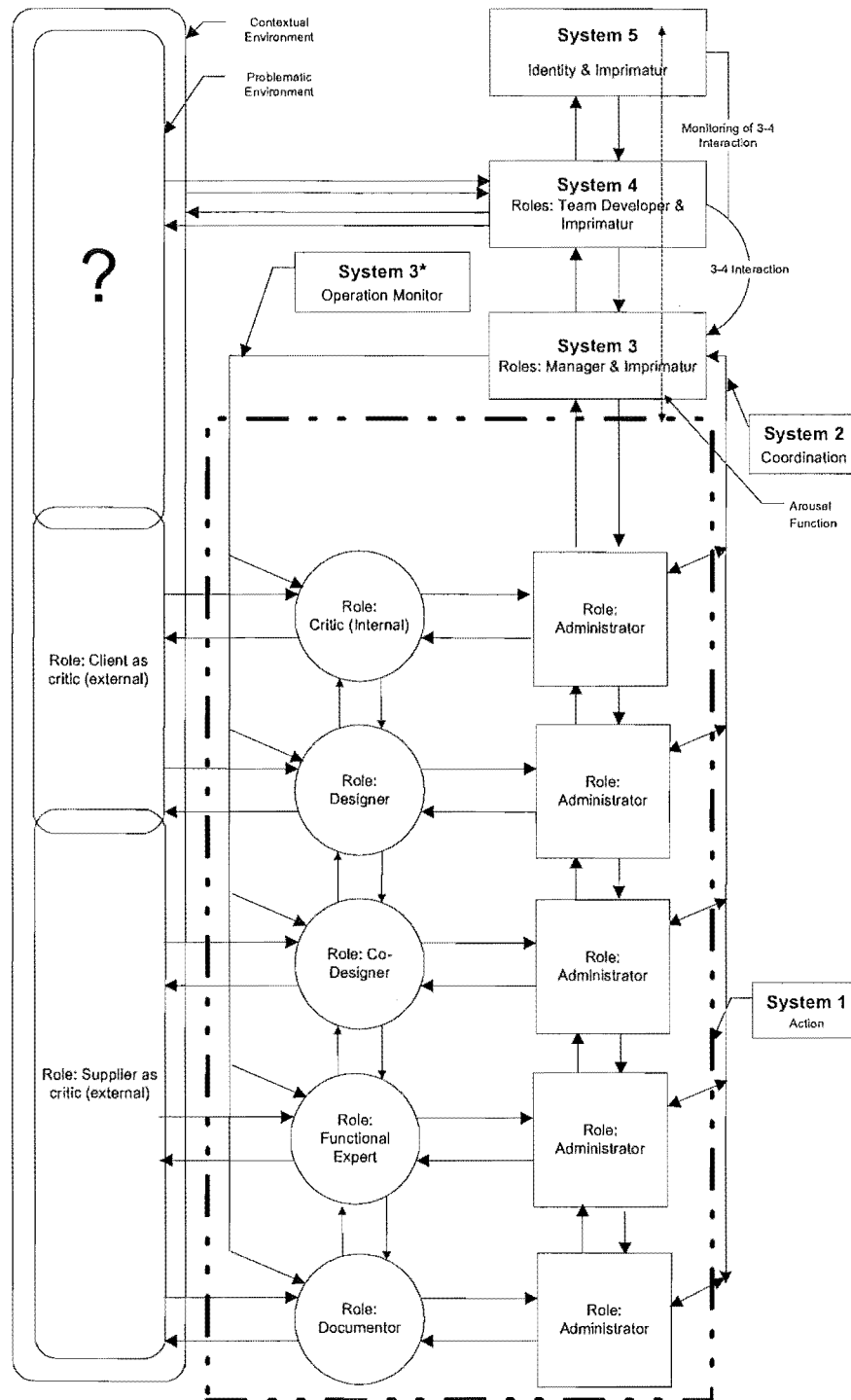


Figure 14. Pre-Production

In Figure 14, the Pre-Production phase, components are proven; the documented output of this phase is a design of a manufactured product. The roles of functional experts and critics are required to produce the pre-production design and the suppliers involved act as external critics to assist System 1; an imprimatur role in System 3 is required to release the production data.

The metamodel presented considers the development of a complete product. Frequently however, a product is separated into sub-components for the purposes of design and manufacture. Therefore, the role of a sub-designer needs to be introduced. The systems associated with the sub-designer's activities perform the same functions as the overall designer but at a lower level in the model. The activities of designers and sub-designers can be linked by employing the recursive structure of Beer's VSM. This concept and the interactions are detailed in Figure 16.

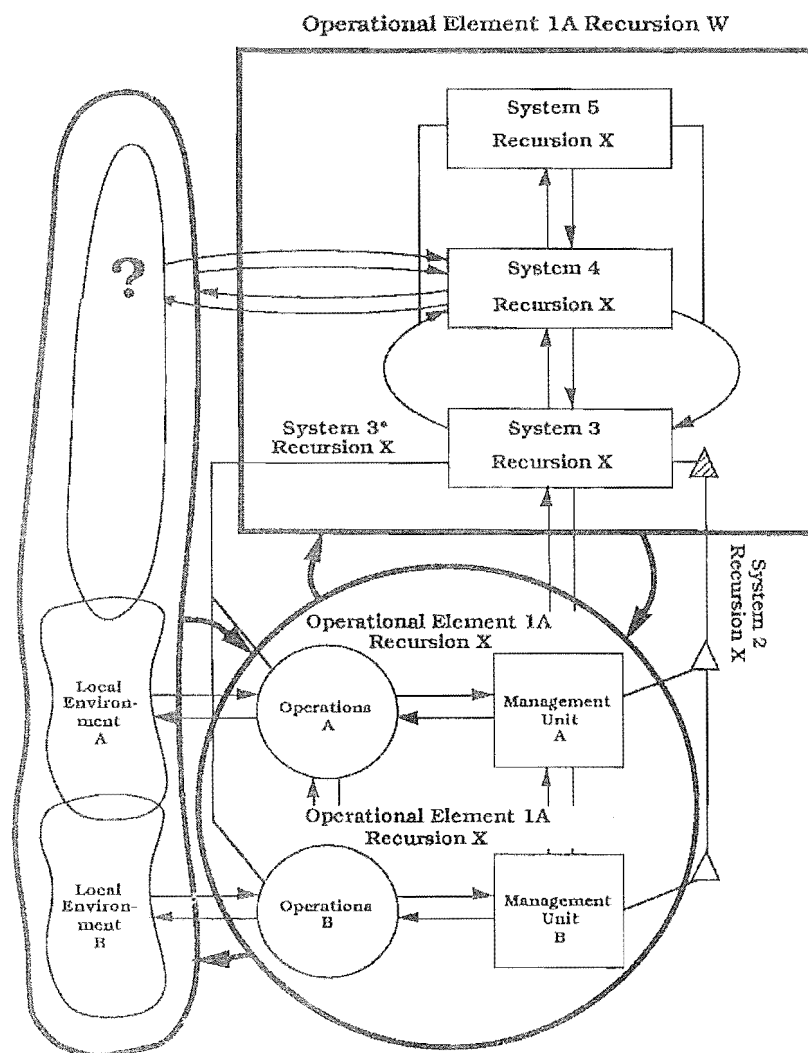


Figure 16. Linking Levels of recursion
(Copied from Garner, 1991, pp.243)

3.6 Justification and composition of the metamodel

It is necessary, at this point, to discuss the justification of the developed conceptual model. Ackoff and Gharajedaghi argue that using the correct model is important, as incorrect models, when used, will result in a system failure due to a mismatch in model types (Ackoff and Gharajedaghi, 2003).

A conceptual model of the product development process that provides context and explains the identification of, and interactions between, classes of data, roles, processes and organisations that use PDM systems has been developed. The models of Beer, Ackoff and Emery and Garner were integrated to develop this model as, individually, each had shortcomings that rendered them incapable of representing the system required. Beer's model, while capable of representing sufficient criteria such that an organisation as a whole is integrated and viable, does not explain the purposeful interactions necessary between individual role players for them to integrate their activities in an organisation. Conversely, Ackoff and Emery's model, while representing the system that ensures effective communication (and hence integration of beliefs and feelings) between purposeful individuals, is not capable of representing sufficient criteria such that an organisation as a whole is integrated and viable. Used together, these models represent an integrated system that accounts for the purposeful nature of the roles in a viable organisation.

However, these combined models are still insufficient to describe a product development process. In this context, the roles associated with the development of the design hypothesis must be determined. These two models were combined with Garner's Purposeful Design Model; the designed interactions between requisite roles of this model ensure that a design hypothesis is effectively integrated throughout the purposeful nature of the roles in a viable organisation. Nevertheless, this combination was still not sufficient to describe the process by which the roles and organisation realise the development of a product. That is, as the product development process progresses to its completion, the required roles and activities change; these changes are unable to be accounted for in the models combined so far. The Dallas modified model of Hales is utilised to account for this shortcoming; the addition of identified roles and activities at particular stages of the product development process enables the representation of the changing nature of roles and activities.

The combination of these models into a new conceptual model explains the identification of, and interactions between, classes of data, roles, processes and organisations; this fundamental conceptual model can now be utilised to identify the data and metadata created during a product development process. These identified attributes can now be utilised to underpin the development of new tools and methodologies to provide PDM function for smaller enterprises.

3.7 Summary

Designed roles and interactions required for the integration of a design hypothesis were identified from Garner's Purposeful Design Model. It was shown that a general model for these interactions could be constructed using the work of Ackoff and Emery and that this communication model could be used to identify data and metadata created if the interactions employed documents as a message medium. These two models were then combined with Beer's VSM to represent a model of a system that is "capable of independent existence" (Espejo and Harnden, 1989) in a changing environment. Finally, all three models were considered within the context of a product development process in order to model the changing roles within an organisation during a product development process.

Thus, the models presented in this chapter have been combined to create a metamodel of an organisation implementing a product development process, accounting for the purposeful nature of participants (the *parts*), as well as the interaction of roles within the organisation (the *whole*). The metamodel identifies classes of data and metadata created during this process.

The models have been developed to aid in the development of computer based tools in order to assist with product data management during the product development process. This model was required as it was concluded that little consideration had been given in the PDM research community to the relationship between classes of data, data users and enterprise structures on the development of the functions and emerging technologies of PDM systems. Before the design of appropriate tools could be considered, a model of the environment in which they were to be implemented was required.

Having modelled the data and metadata created during a product development process, the next chapter uses the classes of data and their modelled interactions to aid in the development of a computer based data management functions in order to assist in the management of a design process.

Chapter 4. Development of computer aided PDM functions

Preceding chapters have identified the need for the development of new systems suitable for use by SMEs that are capable of managing the data created during the development of new products. In order to understand the requirements of such systems, a metamodel of a viable organisation, implementing a product development process and taking into account the purposeful nature of participants (the parts), as well as the interaction of roles within the organisation (the whole) has been developed and presented.

The metamodel identifies data and metadata created and communicated throughout the organisation during a product development process. The model further identifies the mechanisms behind the creation and communication of data between the points at which product definition data are managed by current PDM systems. This fundamental model was required as, to date, reported PDM research has not considered the contextual effect that classes of data, enterprises and people have on the functions and technologies developed for PDM.

This chapter utilises these models to underpin a methodology and software platform suitable for SMEs for the purpose of managing the data within a smaller organisation. The methodology and software platform incorporate the classes and types of data identified in the model and extend the current data managed by available PDM systems; the increased scope of the data available to be managed by the proposed system extends the capability of these systems. Before the methodology and software platform are discussed this chapter firstly presents an example of the use of the metamodel in a real world computer based system. Having identified the classes and communication of data in a real-world example a software system that plans, organises, operates, controls and maintains the data pertaining to a product is developed. Portions of this chapter have been previously published at the International Conference on Engineering Design during 2003 (Shaw and Aitchison, 2003).

4.1 Linking the research model to data management system requirements

The metamodel developed in Chapter Three identifies the necessary interactions of roles in defined organisational systems; the model then accommodates the changing nature of required roles and their place within an organisation's systems as a product development process is undertaken. The idealised model describes the relationship between classes of data, data users and organisational structures during a product development process. The model identifies and classifies potential data that a PDM system could manage as opposed to the current PDM methodologies that manage only specific product definition data.

When computers are used by an organisation a recipient is instructed, informed or motivated when they receive a message consisting of digital data. Metadata relating to the communication of this data can also be recorded, and the information that can be inferred from the metadata can be utilised by other roles or systems in the organisation for various purposes.

One such function is the use of the metadata to assist the management of the data itself. When two roles within an organisation communicate in a digital format (e.g. a CAD file) data are recorded and transferred between the roles. Metadata are created and recorded as these activities take place. This metadata may be generated consciously by a role (e.g. the name of an author or reviewer, a name for the file and the date it was created) and/or it may be created automatically (e.g. by a software program). In a process of digital communication of data between two roles both data and metadata are created. The model created in the previous chapter can be used to identify both the data and the metadata that are created during such a process.

For example, during the detail design stage of a product development process (Figures 13 and 17) a manufacturing functional expert (whose role is to critique the design with regard to its manufacturability) may consider that a change to the detail design of a product definition is required in order to facilitate the better manufacture of the product. To change the product definition the manufacturing functional expert (MFE) role must communicate the proposed change to the co-designer (CoD). That is, an interaction between the two roles must occur.

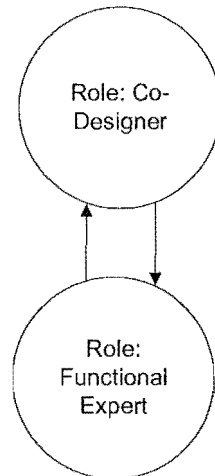


Figure 17. Role Interaction

A message must therefore be passed from the MFE to the CoD; to do this, a method of communication must first be selected by the MFE. The model developed in section 3.5.2 and represented in Figure 5 represents the idealised process by which the manufacturing functional expert selects and executes a form of communication to pass a message about a change to the design. In this example, the selection and execution of a method of communication would proceed as follows:

The MFE first establishes the beliefs and feelings of the CoD towards the MFE:

1. The MFE's beliefs and feelings about the CoD are communicated to the CoD.
2. The CoD develops new beliefs about the MFE (as a result of the communication of the MFE's beliefs and feelings about the CoD and the CoD's own feelings about the MFE).
3. The CoD's new feelings about the MFE (as a result of the CoD's new beliefs about the MFE) and the CoD's new beliefs about the MFE are communicated to the MFE.
4. The MFE develops new beliefs and feelings about the CoD as a result of the communication of the CoD's beliefs and feelings about the MFE.

The MFE then establishes the beliefs and feelings of the CoD towards the proposed change to the design:

- A. The MFE's beliefs and feelings about the proposed change to the design are communicated to the CoD.

- B. The CoD develops new beliefs about the proposed change to the design (as a result of the communication of the MFE 's beliefs and feelings about the proposed change to the design and the CoD's own feelings about the proposed change to the design).
- C. The CoD's new feelings about the proposed change to the design (as a result of the CoD's new beliefs about the proposed change to the design) and the CoD's new Beliefs about the proposed change to the design are communicated to the MFE.
- D. The MFE develops new beliefs and feelings about the proposed change to the design as a result of the communication of the CoD 's beliefs and feelings about the proposed change to the design.

As a result of these steps, the manufacturing functional expert determines a course of action (O_j) to communicate with the co-designer about the proposed change. In the communication model developed, all steps (i.e. 1,2,3,4,A,B,C,D) preceding the determination of the course of action (O_j) are required to ensure the recipient of the communication correctly understands the data that is communicated. Some or all of these steps may be performed in a digital environment; e.g. the two roles may exchange emails that assist in determining their respective beliefs and feelings related to the proposed change. If this is the case, then data and metadata can be recorded as a consequence of these activities.

It should be noted that the steps described in the theoretical model are those necessary to ensure the creation of an effective communication about the change to the design. In a real world situation some of the steps may be omitted. This omission of steps can occur for two reasons. Firstly, the MFE may have previously established the beliefs and feelings of the CoD towards the MFE and the change to the design; hence, these interactions may not be required. Secondly, the MFE may *assume* the beliefs and feelings of the CoD towards the MFE and the change to the design and determine a course of action based on these assumptions. Nevertheless, where data and metadata relating to these activities are created and communicated in organisations, current PDM systems do not yet have the necessary functions for their management.

If the manufacturing functional expert decides to inform the co-designer of the change, a course of action (O_j) may be use of a document created by computer based tools employed for this purpose. If so, metadata can be created and associated with a digital version of this document (Figures 5 and 18) when it is created. A common document used in engineering

organisations for this purpose is the Engineering Change Order (ECO). Note that some organisations *require* that this type of communication be recorded in this format.

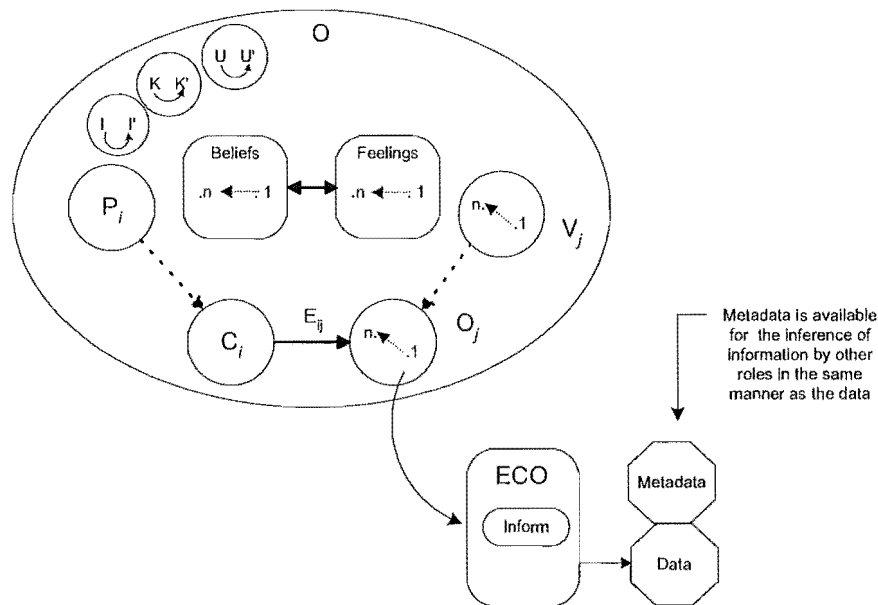


Figure 18. Creation of a document

The metadata recorded and associated with the creation of the document is then available for use by the other roles within the organisation that have access to the computer system. Note that the determination of the type and range of metadata recorded (author, creation date, version, file name, etc.) may vary to suit the needs of various roles.

The document is then received by the co-designer (as detailed in Figures 5 and 19) and, as a result, the co-designer acquires new data from which information relating to the proposed change is inferred: if the communication is effective, the co-designer is informed. Metadata are also created when this document is received (recipient, time received, file name etc.).

Thus, the metadata generated by creating and receiving data in digital form may be acquired by the manufacturing functional expert, the co-designer, as well as other roles in the organisation. Information relating to the activities performed by the interacting roles may then be inferred, both by the roles themselves and other roles within an organisation: data are then available to assist the management of the process itself.

For example, information could be inferred by the administrator role that the co-designer had received an ECO (as the author, name and receipt date of the file is known) and planned

workload of the role subsequently adjusted. Similarly, if the metadata detailed a relationship between the ECO and a particular product (represented by a CAD file) the administrator could ensure the ECO was stored in a particular location, to facilitate use by the co-designer.

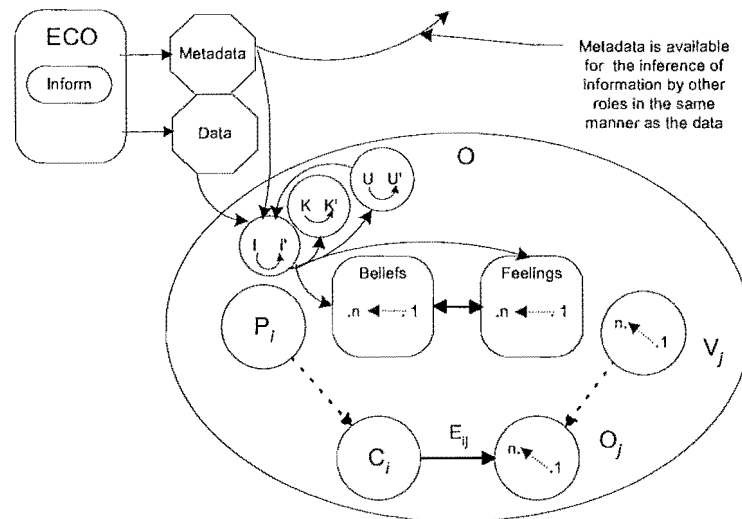


Figure 19. Acquisition of data

All messages created because of the interactions throughout the product development process defined in the metamodel create metadata; in a computer based system, these metadata are available to other roles and information pertaining to the interactions may be inferred. It is the *selection* of the metadata by the system designer that limits the information that is able to be inferred from the activities that occur in a computer based system. Although this example considers metadata associated with the document that is used to communicate a change to the design, it should be noted that metadata may be produced during the preliminary steps to determine the course of action that results in this document. That is, some of the steps may occur in a computer based system; for example the establishment of beliefs and feelings between the CoD and MFE may occur using software. Email and other collaborative software programs are some such examples; hence this metadata may also be utilised by roles within the organisation.

It is the utilisation of metadata that is the basis of functions that PDM systems perform; metadata relating to the creation, communication and access to data are recorded and the

information that is inferred is used to manage the data by the organisation's various systems. It should be noted that, depending on the type of metadata recorded, the information that can be inferred can be used for many purposes by various systems of an organisation. While this thesis investigates PDM functions and the use of metadata for these purposes, the metamodel created in Chapter Three can be utilised to identify interactions where metadata could be of use for other functions of an organisation. Some examples include: costing, resource and project management.

As the model created in Chapter Three identifies data and metadata interactions that occur during the product development process by a viable organisation, the model can be used as a basis for developing PDM functions. This chapter next explores reasons why current software PDM systems are unsuitable for SMEs. This is important as research into the use of technologies such as PDM systems to support product development in SMEs has been largely ignored by the research community (Abramovici and Gerhard, 2000, Caillaud and Passemard, 2001), yet the systems have been shown to be of benefit in reducing the time to market of manufactured products. Smaller Enterprises uptake of newer technologies such as PDM systems may be low due to lack of resources and unsuitability of current methodologies, but these organisations are still likely to benefit from the appropriate management of data and information throughout a product development process.

Secondly, a new methodology for real-time product development process data management for SMEs is introduced and a software platform based on this methodology is presented. The ability of the platform to utilise both descriptive and prescriptive representations of the product development process for the purpose of managing data is then discussed.

4.2 Lack of suitability of current software PDM systems for use in SMEs

Methods suitable for larger organisations are not always directly transferable to smaller enterprises for a number of reasons. SMEs in New Zealand use combinations of paper and software documents to support the strategies, communications, tools and methodologies that underpin the product development processes. The adoption of computers by SMEs to support the product development process has become more prevalent and there has been a corresponding increase in the digital data created throughout the process. This digital data and

information is created, accessed, modified and shared by participants in the product development process. The survey reported in Chapter One indicated that the use of some form of PDM software to control and access product data was limited to very few enterprises in New Zealand. Furthermore, unless in transit between collaborators, data and information were usually stored by software application and/or product attributes (such as a CAD file or project number).

In the absence of any formal systems, control and storage of data and information was more likely to be managed in an employee specific manner (that is, the employee would select the method). Most enterprises recognised this was a problem that would grow as the use of software applications increased, but there was a reluctance to accept the structures imposed by current PDM systems as a solution to the problem. Reasons given were that many tools and methodologies used by larger organisations to manage data were not suitable for SMEs, due to their restrictive nature and that the underlying concepts, structures and applications that are inherent in the PDM systems created for large organisations often made their use in SMEs untenable. The use of PDM software is also one example where smaller organisations have problems providing adequate resources for successful implementation.

Small and Medium Enterprises, by dint of their nature, face hurdles in the implementation of PDM systems that larger organisations can overcome, as they have more resources available. Substantial resources are required for the establishment, configuration and use of PDM systems. SMEs that implement software based systems rely almost exclusively on Commercial Off The Shelf (COTS) software for their computing systems and are unlikely to have the resources and time to establish an in house computer based PDM system. The main differences between larger organisations and SMEs that can have an effect on the development of PDM systems that were identified in the literature review are summarised and where necessary expanded upon in the following sections.

4.2.1 Lack of resources

In addition to resources (personnel, hardware, software etc.) required to establish PDM systems, further personnel resources are required to determine, classify, record and establish relationships between the product data once the system is implemented. All these are activities that need to be completed in order to successfully manage the data that

organisational systems create. Resource availability is a critical factor in smaller organisations; we are all familiar with the term “paperwork” which refers to the administration required by an organisation in order to support the development of an activity. The PDM system requires electronic “paperwork” to be completed in the form of the user interfacing with the system and a lack of resources is a common factor in SMEs. In smaller organisations (as well as other types of organisations) it is not uncommon to find these activities take second place to the actual development of the product artefact.

4.2.2 Management requirements

Current PDM systems are designed for use by larger organisations; their underlying structure is constructed to assist in the management of data and information and address problems inherent in the management of data by large numbers of people cooperating in the development of products. In effect, the structure of a PDM system is used to control users through interaction in a prescriptive manner that is determined by the functions that configure the systems. This type of rigorous approach may not be appropriate for smaller enterprises, as their small size and the ability of participants to interact allows a more flexible approach to product development. Many enterprises in the survey discussed in Chapter 1 said a major strategy was “*working closely together*” and this was seen as a significant advantage. One inference from this statement is that the strategy allowed participants to exchange data and information more readily and in an unconstrained manner. That is, due to the ability to work closely, the enterprises regarded a lack of prescription as an asset that gave them an advantage in product development.

4.2.3 Product oriented structure of current systems

Product data managed by the majority of PDM systems is primarily visualised through a product-oriented structure. That is, metadata detailing the attributes, relationships and lifecycles of documents, products, processes and resources used in the development of a product through all phases of its lifecycle are centred on the artefacts produced. The evolution of PDM systems was such that data management functions preceded the addition of process management functions in the form of workflow. While both systems are used concurrently, present systems still primarily emphasise product data views, while the workflow engine, representing the processes, is very much a secondary function.

4.2.4 Data and information selection

Presently, data managed by enterprises is product oriented and, as discussed in Chapter 3, PDM systems do not manage all the data generated by a typical product development process. Product data managed by PDM systems is that which during the implementation of the system, has been identified as important enough to be managed with respect to the design and manufacture of the product; it is typically data that links the hypothesis development system with the wider organisation and environment. That is, someone, or some people, form a belief that this type of data warrants management. PDM systems do not presently consider other aspects of the product development process data, (non product definition) such as data that is acquired in the course of the process, (e.g. access to information databases, Internet documents), communications and other data that results from the product development process; i.e. data created and communicated within the Hypothesis development system. This is especially true in the earlier stages of the design process where there tends to be a greater percentage of time spent on data gathering and assessment. There is a need to manage and record this information so to more fully represent the product development process. This data would assist in describing both design history and the design rationale behind the product development process, subsequent iterations, and would also be beneficial for supporting the creation of future product developments (e.g. costing and process analysis).

4.2.5 Process workflow

Due to the product centric manner in which data are displayed by PDM systems, current methods do not visualise the creation of product data as a process within the PDM structure. The product centric format cannot be used to represent a product development process, therefore, processes are represented in PDM systems by a workflow. So-called workflow management systems are, it has been argued, an essential software utility for organisations, yet their application within real organisations has been minimal (Agostini and de Michelis, 2000). In current PDM systems for larger enterprises, only the simpler processes associated with product development such as engineering change orders (ECO's) are currently modelled as workflow processes. This methodology has shortcomings when used for the representation of product development processes: the main reason for this is the variable nature of product development activities, (i.e. they are not completely known at the outset of the project). As a

consequence, only the simpler processes where the workflow is invariable, such as ECO's, are currently modelled.

The basis of the existing PDM workflow systems is a *task-oriented* approach. Activities are decomposed into a series of tasks and the documents associated with the task are then managed to facilitate the task – the systems use an “as planned” (i.e. the tasks are pre-determined before the tasks are initiated) approach rather than “as completed” (where tasks are identified after they have been initiated). There is some evidence (Shaw *et al*, 1999) that SMEs utilise goal oriented product data management in preference to task-based management due to the size of the organisations and the environments in which they are conducted. A completed product development programme is thus represented by an ideal “set” of files or documents (at project completion). That is, an *output-oriented* as opposed to a *task-oriented* approach is utilised. At the onset of a programme an “educated guess” of the contents of this set is made. This set of documents may be determined from sources such as:

- Previous product development data sets
- Customer requirements
- Internal administrative requirements
- Quality, Safety and Environmental Management requirements

Thus, management of this set of documents as opposed to the tasks involved, may be more appropriate given the characteristics of SMEs, the unsuitability of current PDM systems used by larger organisations for transfer to the SME environment (reasons for which have been detailed above), and the inability of task oriented workflow to represent a process.

The remainder of this chapter will now develop a method by which SMEs can manage product development process data without the limitations imposed by adopting PDM systems used by larger organisations.

4.3 A Product Data Management architecture for SMEs

For SMEs to leverage advantage from the computer based support of the product development process an alternative to the methods employed by larger organisations must be developed for the reasons stated previously. The novel methodology described below produces a model of the product development process by determining and representing, in real-time, the metadata

associated with documents created with respect to the development process timeline; it is a descriptive model of the process. This approach describes the state of the system; from this description, information can be inferred and, by comparison with information inferred from previous states, required PDM functions can be provided.

This approach necessitates changing the primary emphasis of current PDM systems (association of predetermined metadata with a product structure orientation and workflow) to a temporal representation where the documents are related by virtue of their existence within the project's timeframe. As such, We are interested in; *when* the documents (containing product definition data) were created, *how long* they existed in relation to the overall process timeframe, the participants in the process and desired goals.

To achieve this goal, a primary document relationship is established that is relative to the timeframe of the project under consideration. This methodology will be developed in order to determine whether the aims that were presented in the introduction to this thesis are achievable. That is:

- The investigation of the feasibility of automatically extracting types of metadata (identified from the conceptual model) from the computing environment for the purpose of managing data associated with the product development process.
- The investigation of the feasibility of using a comparison between metadata describing a real-time model of the created design documents and metadata describing a list of planned design documents; the review of metadata generated by this process is then used to determine if visualisation and control of a product development process in smaller enterprises can be achieved.

This methodology makes use of the fact that in a computer based environment the metadata associated with the creation and modification, access, printing and communication of documents are able to be captured. The novel platform developed below initially considers the activities of a single document and its use by participants within the process. It then combines data from additional documents in a bottom up approach to construct a full description of the process in terms of the documents created and communicated. With respect to the category of data managed, the platform extends the type of data that can be managed by a PDM system as

it includes information, communications and other databases that are accessed via computer as part of the product development process. As more and more of these activities are performed within an electronic environment, a more complete descriptive record of the activities associated with the product development process will be able to be determined.

4.4 Establishing a temporal relationship relative to the process timeline

To provide a data workflow management function suitable for SMEs, a graphical representation is proposed to temporally and spatially represent a document's existence, in a computing environment, between single or multiple users with regard to the overall process (Figure 20). Each *single user* creating or manipulating a document in response to activities required by a product development process does so at a particular time relative to the process timeline. A document's active "life" (or period during which a person interacts with it) within the project is represented by a length (equivalent to time t) and this length is then related to the period that it is used (created, used, accessed etc) within the duration of the project (time T , with start at T_0 and end T_{end}). Graphically, this can be represented as shown in Figure 20.

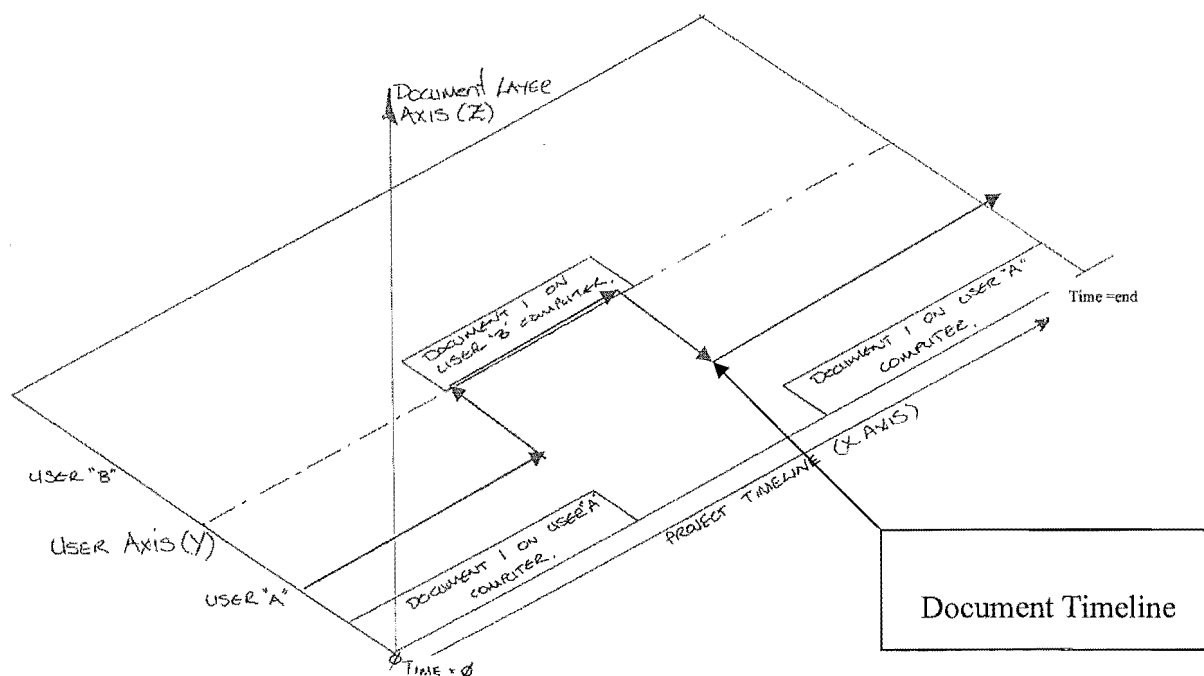


Figure 20. Graphical Representation of a single document along a process timeline between two users

As more documents are created in the product development process, they are viewed relative to the original timeframe and existing documents. In the graphical representation overleaf, further layers, representing additional documents, are added along the Z axis. The documents are not represented when they are stored, only when they are being “used” by participants. In effect, a “map” of the activities (creating and modifying data, accessing information, communication), denoted by the use of documents which are associated with the development process, is created in relation to the timeframe of the process. For more than one user the “Y” axis is extended to record additional personnel involved in the process.

Furthermore, as each additional document is added in the process it is represented on additional layers in the Z axis. Documents that are transferred between participants of the process are registered on the new users “map” and a serial trail between different users can be established. This trail assumes that no concurrent manipulation of documents by users occurs, however, it can be seen that multiple concurrent use of a single document can be represented by this schema. This feature will become more important as the tools to enable concurrent viewing and manipulation of digital documents are further developed and become more widespread. At present, this type of collaboration is in its infancy.

Once the initial relationships between documents has been established, relative to a process, the metadata associated with these relationships can be used for further PDM purposes. That is, for author X at time t_x working on a particular document we can access metadata such as document location, current revision status, etc. from available metadata. This metadata will enable functions such as versioning and revision control to be implemented.

4.5 Metadata extraction

The functions inherent in PDM systems can be implemented in a number of ways and need not involve the use of so called information technologies (IT) (Helms, 2002). A core tenet behind the operation of current software based PDM is the use of metadata to enable the functions associated with PDM systems to be implemented. Typically, PDM software packages utilise a relational database containing stored metadata to manage associations between object attributes; the metadata are gathered from both user input and system activities.

SMEs can (and frequently do), provide some PDM functions within their organisations without the use of a relational database. Management can be achieved through many methods and two common methods are described as follows:

- Provision of metadata through association with location, that is, information can be inferred for PDM purposes from knowing the location of data. A designated file location can provide information relating to a file's lifecycle or status (e.g. a file in location X connotes that it is "Obsolete", a file in location Y connotes that it is "Approved for Production") and the location of a file amongst others can provide information pertaining to product structure.
- Metadata are combined with data and stored in the file itself or a separate file (e.g. author, date, drawing number etc). This metadata becomes available when the appropriate file is accessed.

These two methods, together with either paper based methods or commercial off the shelf software (COTS) and the use of appropriate protocols can provide functions similar to those offered by extant PDM systems (e.g. version and lifecycle management). These solutions, however, lack some advantages gained by using the relational databases of current PDM systems (e.g. attribute searching and replacement facilities) and the workflow functions are typically not available. However, SMEs can and do successfully use these simple systems despite their shortcomings.

To provide a descriptive model of the product development process (or descriptive workflow) as well as data that can be used to provide PDM functions, metadata associated with the process timeline can be extracted from within document files as well as from the operating system itself. This extraction process can be automatically implemented in real time as the software metadata extractors can monitor the user's computing environment. Descriptive workflow data are collected when a file is accessed in a computing environment and cumulative data associated with discrete time intervals can be used to determine the period that a document exists in a digital environment. Further metadata are captured at these points to provide data for PDM functions. This data includes:

- File Creation Date/Time,
- File Open Date/Time,

- File Close Date/Time,
- File Modified Date/Time,
- File Printed Date/Time,
- Current Author,
- Document Location.

Additional metadata are also frequently available in document files from specific software packages which may be used. For example, the CAD program Solid Edge provides the ability to record revision lifecycle data within the document itself.

This approach has an advantage over current PDM systems that explicitly specify the metadata that is collected. That is, metadata able to be utilised by current PDM systems is determined and fixed at the time of installation/configuration. These systems can only infer information from a limited pool of available metadata. With the method described above available information is not limited to that able to be provided from a specific pool of metadata; the user has access to other types of metadata that may provide information to more readily perform the functions of a PDM system.

4.6 A platform for real-time rapid product development process data and information management

A platform for real-time rapid product development process data and information management is presented in Figure 21. This platform is designed so that it is extendable to operate with different operating systems and document file formats, by accessing standard formats and protocols used in these functions by the computing software industry. The platform is a stand alone unit which is associated with an individual computer and, by aggregating metadata from multiple computers, can be extended for use over a network.

The document metadata are gathered by using two separate software modules. Module 1 works on the document layer and parses the metadata. Module 2 data mines the operating system information for available metadata. These two modules operate in real-time to continuously poll the computing environment and are described in more detail below.

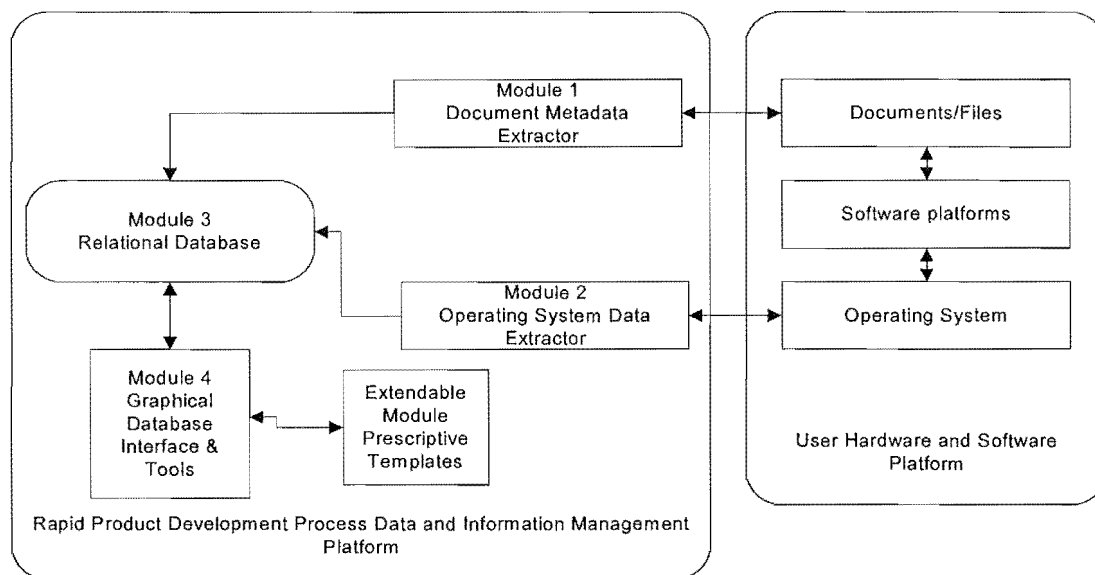


Figure 21. Software platform for real-time rapid product development process data and information management

Module 1 is a parser that reads the metadata relating to the creation, access and modification of document files which is contained within a document file. This is performed in real-time and passes this information for storage in Module 3 where it is related to the project timeline. The parser utilises the fact that files contain industry standard common metadata such as “author”, “date created” etc.

Module 2 accesses the operating system of the user in real-time to provide further data relating to activities associated with documents that are performed on the system which are not contained within the documents themselves. This is performed in real-time and the module passes this information for storage in Module 3. This extractor utilises security functions contained within all operating systems that are a standard within the industry.

A further two software modules collate, store and present the metadata to assist in the provision of PDM functions. Module 3 is a relational database or spreadsheet used to collate the metadata, establish a relationship between the metadata and the process timeline and store the real time data. Module 4 uses the data contained in the relational database to construct a graphical interface to present the data in a temporal and spatial configuration. Based on the representation developed in Figure 20, a 3D world is proposed as a method for visualising the data. The world will represent the “product development process space” and the objects

within the world represent the data created. As the model is in 3D, CAD analysis and verification techniques such as a “walk through” can be implemented, adding to the utility of the model. Similarly, maintained hyperlinks can be invoked to enable the examination of individual documents.

This platform is extendable to make further PDM and other management functions possible. An additional module, detailed in Figure 21 and called “Prescriptive Templates” is utilised to provide workflow functions. The use of this module is detailed in section 4.7 below. The platform is extendable through the addition of further modules with additional functions based on the metadata collected e.g. optimisation, costing etc.

4.7 A module for descriptive and prescriptive maps of product development.

A *descriptive* model of the product development process can be created in terms of the documents created and accessed as part of that process. Section 4.2.5 of this chapter suggested that SMEs utilise a “goal oriented” approach to the creation of documents for product development processes. That is, enterprises have a *prescriptive* list of documents that must be completed to indicate that a particular process is complete. The enterprises have a template of what they consider is a “document set” at the completion of a process. They may not know *what* the documents contain, nor *who* will create them but they have established that they *will exist* at points throughout the process and at the completion of the project. This fact is used to create a template that can determine what documents can be required and which are associated with particular temporal points in the product development processes, that is: a prescriptive model. This template can then be compared with the descriptive model that is built up in real time to provide real-time data for workflow management purposes. For example, at the conclusion of the propel phase of a simple product the document set may consist of; a text document containing a description of the product proposal, a CAD file containing a representation of a design and a text document containing a description of the costs involved.

As the product development proceeds, the “as created” set of documents is continually compared to the “as required” document template map. It is possible that this structure will more fully describe the product development process than present methods do, and in a

manner more suitable to SMEs. The model will provide some of the process functions associated with existing PDM systems available to large organisations. Furthermore, as the model is generated in real-time, from available metadata, without user involvement, it is considered that this approach will not tax the resources of SMEs. Thus, the advantages realised by larger organisations in reducing the product development cycle through the implementation of PDM systems will be available to smaller organisations. Finally, it should not be overlooked that this representation and the manner in which the model is created can provide another tool for design and manufacturing process researchers to investigate the methodologies behind the processes involved.

4.8 Summary

Chapter Three developed a systems based metamodel for the purpose of identifying data and metadata interactions during a product development process by a viable organisation. Having identified the nature of the metadata interactions of an organisation during a product development process, this chapter established the link between the metadata and its use in the provision of information to assist the management of data. It was noted that the metamodel was also capable of identifying metadata that could be made available for use within an organisation for purposes other than PDM.

Based on the results of the survey of the characteristics of SMEs in New Zealand presented in Chapter One, this chapter argued that current software PDM systems used by large organisations are unsuitable for use in a SME environment. An alternative method for representing a product development process was described. This method monitored the real-time status of product development documents and inferred information from all available metadata as opposed to the predetermined set used by current PDM systems. Examples were described the method by which information required for the provision of PDM functions could be inferred from available metadata. A software platform to implement this methodology was then presented. A methodology that compared a real-time descriptive representation of the product development process to a prescriptive representation in terms of document use was then introduced as an example of the platform's use in visualisation and workflow management of a product development process data. The next chapter will discuss the implementation of the software platform and the results obtained from the monitoring of the data created.

Chapter 5. Metadata Extraction and Case Study

The previous chapter developed a software platform for real-time provision of metadata for product development process data management functions. To extract this metadata required to support PDM functions a type of monitoring software called Spyware has been utilised. Spyware, in its current usage, has until now been predominantly used to monitor computers and allow third parties to observe users' internet and software use; usually to provide evidence of suspected wrongdoing or assist in marketing functions. To collect this data, the monitoring software identifies and captures metadata generated by the operating system: exactly the type of function required by the framework developed in the previous chapter. This tool was recognised as having potential for incorporation into a methodology to provide PDM functions to be implemented by SMEs due to its low cost (less than \$200USD) and resource requirements (operating without user intervention and using widely available COTS common to most organisations). Furthermore, its ability to gather data from multiple sites made it ideal for managing data over a global computer infrastructure. Thus, this software is being used to observe the data created during a product development process in real time.

5.1 Observation based studies

Hales notes that, from an engineering design point of view, observation based studies may be divided into three categories (Hales, 1986, pp.B1):

- Direct observation (observer removed from process under study)
- Participant observation (observer takes part in process under study)
- Action research (observer takes part and seeks to improve process under study – a Soft Systems Methodology developed by Peter Checkland (Checkland and Holwell, 1998))

All three categories of observation can be associated with differing degrees of researcher involvement and outcomes; each category generating both benefits and detriments. The research presented in this thesis can be categorised as direct observation. At first glance, it may seem that only direct observation could be assisted by the use of this proposed methodology. However, the writer considers that all three types of observation based studies could be augmented with the use of monitoring software; that is, the monitoring software would assist in both the observation of the activities performed and the collection of data

associated with the observations. The software enables the participant observer and action researcher to automatically record activities and interactions that occur, leaving them free to concentrate on the other techniques that need to be applied during that type of research.

The limitation of the software; that is, the constraint of being only able to observe and record activities occurring in a digital environment, constrains potential research applications. The information sought is limited to questions starting with *who?*, *when?*, *how many?* and *what?* in relation to records of the activities performed in a computing environment. However, as discussed above, the increase of digitally based design processes and interactions in the future may yet see this type of software more fully utilised. Furthermore, if research programs are developed with this methodology in mind, other, more targeted research, may be planned and implemented. It should be noted that the methodology is equally applicable in both natural and contrived environments for the purposes of research.

5.2 Experimental setup

Spyware is an emotive word. However, it was decided to use this term instead of “monitoring software” when presenting the research project as it was felt that the people being observed would more easily understand the function of the software. The majority of users had previous exposure to malicious Spyware and were aware of its capabilities. Nevertheless, an awareness programme was developed before implementation of the monitoring software.

5.2.1 Ethical Considerations

Before the monitoring software could be implemented, two questions were required to be addressed. The first, to ensure the work was conducted with appropriate regard for ethical standards and cultural values, concerned the University of Canterbury Human Ethics Committee (HEC). The relevant policy paper was reviewed (Human Ethics Committee, 2004) and it was determined that the experimental setup was exempt from review and approval by the HEC under Section 3(f) of the policy that concerned “...Case studies of business organisations and institutions unless the project involves gathering personal information of a sensitive nature about or from individuals”.

Secondly, an opinion was sought as to the ownership of the data created by the organisation. In New Zealand, where this methodology was implemented, all data generated and recorded

by an organisation's software and hardware is regarded as the property of the organisation. This is not dissimilar to the case in many overseas countries. Before the study commenced, it was decided that all participants were to be informed of their rights with regard to the ownership of data. This ownership also required that other laws needed to be considered such as those relating to Privacy and Intellectual Property (IP).

5.2.2 Informing the participants

The organisation that was to be studied had not fully implemented and documented an IT policy. So, the existing draft policy and associated procedures were subsequently rewritten and clauses added relating to the use of monitoring software by management. Training sessions were then held to inform staff of policy and procedures relating to IT within the organisation. At the same time the intent and functions of the monitoring software were discussed with staff. The organisation's IT policy allowed for personal, but not excessive, use of the IT facilities; activities such as banking and communication were understood to be allowable but excessive use of these facilities were recognised by staff as being not allowed. Staff were competent IT users and understood that IT traffic was already visible to management before the implementation of the monitoring software. It should be noted that this was a tight-knit team that had every confidence in managerial decisions that were made: to these people, the monitoring software was another tool to enable management to better plan and implement strategies to ensure their organisation's future.

In addition to the monitoring software introduction and training, a "splash screen" was enabled at the start of each and every user's computing session, this informed personnel that their activities were being monitored as part of a research project and users had to acknowledge physically the message before the screen would disappear. Apart from this screen there were no other apparent signs that monitoring was taking place – the software operated in "stealth mode" with executable and data files being hidden from all users. The software itself was found to have negligible effect on system transfer speeds and the space required to store the data was easily accommodated by the server. The Spyware was further configured so that individual keystrokes and screenshots of current work were not recorded, that is, only metadata was recorded, the data within files (which could be of a personal nature) was not subject to identification. All collected data were subsequently stored in a secure environment with access restricted to the researcher.

Informal polls of the participants were taken during the study. Anecdotal evidence suggested that the splash box was “just another click” in a computers start-up procedure and no other effects were noticed. Data from an initial two week monitoring period showed little use of the internet for personal purposes; subsequent weeks however indicated increased use for personal activities such as banking, communication, and personal data acquisition. It is suggested that this characteristic be used in future studies as a benchmark measure of the period it takes for users to become accustomed to the presence of the monitoring software. If so, then this type of project would possibly require approval from the HEC.

5.3 Implementation of Monitoring Software

In this research application, monitoring software was installed into a twelve person product design studio for a period of 22 weeks. Work by the team involved all aspects of a design process from conceptual to detail design and frequently included prototyping activities. Products regularly combined mechanical, electrical and software components for different end uses. Typical projects were completed over periods ranging from 6-24 months. The enterprise had previously implemented locative and descriptive methodologies to provide simple product data management functions; these protocols and locations were identified to facilitate the management of the data.

Installed on a central server, the monitoring software recorded system metadata generated as participants interacted with software to perform tasks as part of a product development project. The software proved capable of capturing metadata as depicted Module One of Figure 21. Metadata contained within the document itself (corresponding to Module Two of Figure 21) was not, at this point, extracted from the system as the COTS Spyware did not support these functions and metadata such as Author, Creation Date etc. was able to be directly obtained from the Operating System (OS). It should be noted however, that software to extract this metadata is widely available and could be used to augment the OS metadata; the experimental work described below was carried out solely using system metadata.

Using the OS metadata, all computer activity was able to be observed, e.g., activities such as communication (email, fax) and document creation (CAD/CAM, analysis, reports, etc). Local and global information acquisition and communication (internet, email) activities were similarly recorded. Data was captured in real-time and was batched and automatically

emailed to the research location some five kilometres away. At no time were employee resources required for this process.

The monitoring software was able to capture metadata associated with participants' use of documents and digital records that were associated with the project during its timeframe. Specifically, the metadata captured for each computer activity was:

- Date of activity
- Start Time of application
- Duration of use of application and file
- Host Computer Name
- User Name
- Application Used
- Active Window Name e.g. a file running under a particular application
- URL description – Both intra and inter net URLs were captured
- Main Window Name e.g. a particular application window

An example of the type and range of metadata collected is detailed in Figure 22 (Please note that employee names and URL descriptions have been altered for publication). A further function offered by the monitoring software, that of recording all keystrokes and mouse clicks, was disabled for the study as it was felt that enabling this function would:

- impact security (enterprise passwords would be recorded)
- deter users (as recording of personal passwords and messages would occur) and
- require large amounts of additional mass storage space

However, if utilised, this data could provide further metadata for PDM purposes as useful metadata will frequently be contained within combinations of keystrokes associated with a document or file. The software was also configured to record periods where there was no user interaction with the computer, i.e. the computer was on but not being used. Data was gathered on a central server in real-time from both mobile laptops and office computers. A facility within the monitoring software enabled the data gathered to be scheduled for automatic email to the offsite researchers in real-time.

	A	B	C	D	E	F	G	H	I	J	K	L
	Date	Start Time	Duration	Computer	User	Application	Active Window	URL				Main Window
302	15/06/2004	2:13:05 p.m.	0:01:50 LOAN	Xenophon		C:\outlook	[No user activity]	[N/A]				Inbox - Microsoft Outlook
303	15/06/2004	2:13:08 p.m.	0:05:53 PC3	Thucydides		C:\Word	[No user activity]	[N/A]				[No user activity]
304	15/06/2004	2:15:33 p.m.	0:00:53 LOAN	Xenophon		C:\Solidworks	Company Contacts - Microsoft Ou	[N/A]				Microsoft Excel
305	15/06/2004	2:16:38 p.m.	0:03:06 LOAN	Xenophon		C:\Solidworks	[No user activity]	[N/A]				Microsoft Excel
306	15/06/2004	2:19:01 p.m.	0:07:00 PC3	Thucydides		C:\Excel	Company Contacts - Microsoft Ou	[N/A]				[N/A]
307	15/06/2004	2:19:46 p.m.	0:02:41 PC5	Diego Hurtado de Mendoza		C:\Matlab	[No user activity]	[N/A]				SolidWorks 2003
308	15/06/2004	2:19:59 p.m.	0:00:40 LOAN	Xenophon		C:\Photoshop	[N/A]	[N/A]				Microsoft Excel
309	15/06/2004	2:20:42 p.m.	0:02:15 LOAN	Xenophon		C:\Photoshop	[No user activity]	[N/A]				Inbox - Microsoft Outlook
310	15/06/2004	2:22:27 p.m.	0:03:01 PC5	Diego Hurtado de Mendoza		No User Activity	Inbox - Microsoft Outlook	[N/A]				SolidWorks 2003
311	15/06/2004	2:23:09 p.m.	0:00:49 LOAN	Xenophon		C:\Word	Company Contacts - Microsoft Ou	[N/A]				[No user activity]
312	15/06/2004	2:24:24 p.m.	0:01:15 LOAN	Xenophon		C:\Excel	[No user activity]	[N/A]				[N/A]
313	15/06/2004	2:25:28 p.m.	0:05:44 PC5	Diego Hurtado de Mendoza		C:\office	aaaaaa	[N/A]				SolidWorks 2003
314	15/06/2004	2:25:39 p.m.	0:01:55 LOAN	Xenophon		C:\Matlab	[N/A]	[N/A]				[No user activity]
315	15/06/2004	2:26:01 p.m.	0:03:01 PC3	Thucydides		C:\Matlab	[No user activity]	[N/A]				[No user activity]
316	15/06/2004	2:28:01 p.m.	0:01:08 LOAN	Xenophon		No User Activity	[No user activity]	[N/A]				Inbox - Microsoft Outlook
317	15/06/2004	2:29:02 p.m.	0:30:04 PC3	Thucydides		No User Activity	[N/A]	[N/A]				Company Contacts - Microsoft Outlook
318	15/06/2004	2:29:44 p.m.	0:00:36 LOAN	Xenophon		C:\office	Inbox - Microsoft Outlook	[N/A]				[No user activity]
319	15/06/2004	2:31:14 p.m.	0:00:42 PC5	Diego Hurtado de Mendoza		C:\office	guide sketch of face curve	[N/A]				[No user activity]
320	15/06/2004	2:31:23 p.m.	0:00:38 LOAN	Xenophon		C:\office	[No user activity]	[N/A]				[N/A]
321	15/06/2004	2:32:01 p.m.	0:00:34 PC5	Diego Hurtado de Mendoza		C:\office	Sketch3	http://www.canterbury.ac.nz/				Screen Saver
322	15/06/2004	2:32:58 p.m.	0:00:49 LOAN	Xenophon		C:\office	[N/A]	[N/A]				[No user activity]
323	15/06/2004	2:33:06 p.m.	0:01:26 PC5	Diego Hurtado de Mendoza		C:\outlook	Sketch1 of Part1	[N/A]				Time Discipline Timesheet
324	15/06/2004	2:34:46 p.m.	0:00:36 PC5	Diego Hurtado de Mendoza		C:\outlook	Sketch3	C:\Documents and Settings\All Users				[No user activity]
325	15/06/2004	2:35:27 p.m.	0:03:01 PC7	Usamah Ibn-Munqidh		C:\Solidworks	Sketch3	[N/A]				Inbox - Microsoft Outlook
326	15/06/2004	2:35:59 p.m.	0:01:40 LOAN	Xenophon		C:\outlook	[No user activity]	[N/A]				Inbox - Microsoft Outlook
327	15/06/2004	2:36:17 p.m.	0:01:36 PC5	Diego Hurtado de Mendoza		C:\Solidworks	Sketch3	http://www.canterbury.ac.nz/				Screen Saver
328	15/06/2004	2:37:39 p.m.	0:00:35 LOAN	Xenophon		C:\outlook	Company Contacts - Microsoft Ou	[N/A]				Microsoft Excel
329	15/06/2004	2:37:57 p.m.	0:03:53 PC5	Diego Hurtado de Mendoza		C:\Solidworks	Sketch3	http://www.canterbury.ac.nz/				Microsoft Excel
330	15/06/2004	2:38:28 p.m.	0:33:49 PC7	Usamah Ibn-Munqidh		C:\Photoshop	MSN Hotmail - Message - Microsc	[N/A]				[No user activity]
331	15/06/2004	2:38:42 p.m.	0:00:38 LOAN	Xenophon		C:\Solidworks	Contacts - Microsoft Outlook	[N/A]				Microsoft Excel
332	15/06/2004	2:41:15 p.m.	0:01:11 LOAN	Xenophon		C:\Solidworks	[No user activity]	[N/A]				[No user activity]
333	15/06/2004	2:42:17 p.m.	0:02:47 PC5	Diego Hurtado de Mendoza		C:\Photoshop	bggbg	http://www.canterbury.ac.nz/				SolidWorks 2003
334	15/06/2004	2:42:26 p.m.	0:01:43 LOAN	Xenophon		C:\Photoshop	aaaaaa	[N/A]				[N/A]
335	15/06/2004	2:44:09 p.m.	0:01:53 LOAN	Xenophon		C:\Photoshop	aaaaaa	[N/A]				[No user activity]
336	15/06/2004	2:45:14 p.m.	0:05:12 PC5	Diego Hurtado de Mendoza		C:\Photoshop	Sketch3	http://www.canterbury.ac.nz/				Microsoft Excel
337	15/06/2004	2:46:08 p.m.	0:00:48 LOAN	Xenophon		C:\Word	aaaaaa	[N/A]				Company Contacts - Microsoft Outlook
338	15/06/2004	2:46:56 p.m.	0:02:13 LOAN	Xenophon		C:\Excel	aaaaaa	[N/A]				[No user activity]
339	15/06/2004	2:49:09 p.m.	0:03:23 LOAN	Xenophon		C:\Matlab	aaaaaa	[N/A]				Company Contacts - Microsoft Outlook
340	15/06/2004	2:51:16 p.m.	0:02:01 PC5	Diego Hurtado de Mendoza		C:\Word	Sketch3	[N/A]				Screen Saver
341	15/06/2004	2:52:32 p.m.	0:04:56 LOAN	Xenophon		No User Activity	aaaaaa	[N/A]				[No user activity]
342	15/06/2004	2:53:20 p.m.	0:04:09 PC5	Diego Hurtado de Mendoza		C:\Excel	MSN Hotmail - Message - Microsc	[N/A]				[No user activity]
343	15/06/2004	2:57:28 p.m.	0:01:59 LOAN	Xenophon		C:\office	[No user activity]	[N/A]				Company Contacts - Microsoft Outlook
344	15/06/2004	2:57:57 p.m.	0:03:01 PC5	Diego Hurtado de Mendoza		C:\Matlab	Inbox - Microsoft Outlook	[N/A]				Inbox - Microsoft Outlook
345	15/06/2004	2:59:06 p.m.	0:05:05 PC3	Thucydides		C:\office	[No user activity]	[N/A]				[No user activity]
346	15/06/2004	2:59:27 p.m.	0:01:28 LOAN	Xenophon		C:\office	aaaaaa	[N/A]				Company Contacts - Microsoft Outlook
347	15/06/2004	3:00:58 p.m.	0:09:24 PC5	Diego Hurtado de Mendoza		No User Activity	Microsoft Excel	[N/A]				SolidWorks 2003
348	15/06/2004	3:01:53 p.m.	0:01:16 LOAN	Xenophon		C:\office	[No user activity]	[N/A]				[Start menu]
349	15/06/2004	3:03:09 p.m.	0:00:44 LOAN	Xenophon		C:\outlook	Inbox - Microsoft Outlook	[N/A]				[No user activity]

Figure 22. Examples of the type and range of collected metadata

5.4 Captured Data

Once the data had been captured, it required post processing to enable useful information to be inferred for product data management purposes. Data was able to be sorted at two levels. Firstly, the COTS software monitoring program had inbuilt functions for this task; metadata was stored in a (small) spreadsheet type program where filter and sort functions were available. Secondly, as the output files used commonly available formats the captured metadata was easily exported into a native format of Microsoft Excel. This enabled analysis and sorting of the metadata to be completed with a wider selection of data filtering/sorting functions available. A further option, of exporting data to a relational database such as those used by typical PDM systems was not employed at this stage. However, the advantages of employing this method should be considered in future work.

Data was sorted and filtered using the metadata attributes detailed in Figure 23 and multiple attributes were able to be combined for manipulation of the data. Using these techniques, subsets of the metadata were able to be collated and, with subsequent reference to timesheets, associated with particular projects. That is, the metadata was able to identify groups of files associated with specific projects and activities.

	A	B	C	D	E	F	G	H	I	J
1	Date	Start Time	Duration	User	Application	Active Window	Keystro	URL		
42	15/06/2004	11:51:10 a.m.	0:01:08	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
1606	16/06/2004	1:55:18 p.m.	0:02:28	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
1607	16/06/2004	1:55:18 p.m.	0:02:28	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
3688	17/06/2004	8:51:03 a.m.	0:01:21	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
3687	17/06/2004	9:31:49 a.m.	0:03:26	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
3698	17/06/2004	2:51:52 p.m.	0:00:57	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
3699	17/06/2004	3:26:25 p.m.	0:00:31	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
3700	17/06/2004	3:44:51 p.m.	0:01:14	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
3701	17/06/2004	3:15:50 p.m.	0:00:42	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
7241	21/06/2004	10:07:59 a.m.	0:00:49	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
7251	21/06/2004	4:39:15 p.m.	0:01:56	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
9155	22/06/2004	8:11:30 a.m.	0:01:26	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9186	22/06/2004	9:28:34 a.m.	0:03:01	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9187	22/06/2004	9:40:27 a.m.	0:02:55	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9188	22/06/2004	10:32:52 a.m.	0:01:09	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9189	22/06/2004	10:52:20 a.m.	0:03:01	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9190	22/06/2004	11:38:11 a.m.	0:01:30	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9191	22/06/2004	12:12:26 p.m.	0:02:08	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9192	22/06/2004	2:44:57 p.m.	0:02:56	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
9207	22/06/2004	3:46:11 p.m.	0:03:31	PC6 Francesco Balbi di Correggio	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\CH		
9282	22/06/2004	3:05:45 p.m.	0:01:14	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
10923	23/06/2004	12:47:30 p.m.	0:00:51	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
10924	23/06/2004	2:52:43 p.m.	0:01:08	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
10925	23/06/2004	3:44:56 p.m.	0:02:54	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
12613	24/06/2004	12:40:32 p.m.	0:03:07	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
12614	24/06/2004	4:13:11 p.m.	0:00:41	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
14504	25/06/2004	8:26:46 a.m.	0:03:01	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
14505	25/06/2004	8:56:07 a.m.	0:01:38	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
18141	28/06/2004	4:57:57 p.m.	0:00:32	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
18214	29/06/2004	10:17:38 a.m.	0:05:16	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
18215	29/06/2004	10:58:19 a.m.	0:03:09	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
18690	30/06/2004	5:45:35 p.m.	0:03:04	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
18991	30/06/2004	3:46:09 p.m.	0:04:48	PC3 Josephus	Explorer.EXE	MASTER Released		MASTER Released		
18994	30/06/2004	2:30:04 p.m.	0:01:10	PC13 Andrew Wheatcroft	Explorer.EXE	MASTER Released		P:\MASTER Released		
18995	30/06/2004	2:31:48 p.m.	0:00:50	PC13 Andrew Wheatcroft	Explorer.EXE	MASTER Released		P:\MASTER Released		
18996	30/06/2004	2:33:02 p.m.	0:00:32	PC13 Andrew Wheatcroft	Explorer.EXE	MASTER Released		P:\MASTER Released		
21917	1/07/2004	3:43:14 p.m.	0:02:32	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
21918	1/07/2004	4:16:10 p.m.	0:03:01	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		
21919	1/07/2004	4:25:38 p.m.	0:01:52	PC11 Xenophon	Explorer.EXE	MASTER Released		G:\PROJECTS\SP112\DC		

Figure 23. Metadata providing information associated with the release of a file

As this organisation used locations on the file server to denote the status of a particular file the metadata could identify a change in this document status through the movement of the file. Employees used the program “Windows Explorer” to physically move files between locations and these movements could be determined by sorting the active window and URL attributes.

It proved possible to track the progress of a document as it was created, amended and/or used by different participants during the course of a project. Figure 24 tracks a Solidworks file named “P051-001” over a period of four days and three different users. In total, this particular file was interacted with 473 times during an 8-week period.

	A	B	C	D	E	F	G	H	I	J
1	Date	Start Time	Duration	Con	User	Application	Active Window	Keystro	URL	
25382	15/06/2004	9:26:43 a.m.	0:03:12	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25383	15/06/2004	11:01:42 a.m.	0:01:00	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25384	15/06/2004	11:58:21 a.m.	0:01:18	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25385	15/06/2004	12:55:07 p.m.	0:01:40	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25386	15/06/2004	1:22:57 p.m.	0:00:57	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25387	15/06/2004	1:23:59 p.m.	0:02:28	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25388	15/06/2004	1:42:53 p.m.	0:00:39	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25389	15/06/2004	1:43:38 p.m.	0:00:36	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25390	15/06/2004	1:44:25 p.m.	0:03:10	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25391	15/06/2004	3:01:53 p.m.	0:01:16	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25392	15/06/2004	3:04:16 p.m.	0:07:06	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25393	15/06/2004	3:11:25 p.m.	0:01:43	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25394	15/06/2004	3:35:51 p.m.	0:01:38	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25395	15/06/2004	4:03:52 p.m.	0:00:57	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25396	17/06/2004	10:04:29 a.m.	0:00:45	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25397	17/06/2004	10:05:29 a.m.	0:00:50	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25398	17/06/2004	10:12:48 a.m.	0:00:39	PC4	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-001			
25399	17/06/2004	10:19:47 a.m.	0:00:57	PC11	Thucydides	SLDWORKS.exe	P051-001			
25400	17/06/2004	10:21:10 a.m.	0:00:50	PC11	Thucydides	SLDWORKS.exe	P051-001			
25401	17/06/2004	12:53:10 p.m.	0:00:59	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25402	17/06/2004	2:54:39 p.m.	0:02:34	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25403	17/06/2004	2:57:44 p.m.	0:03:33	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25404	17/06/2004	3:04:25 p.m.	0:00:35	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25405	17/06/2004	3:26:13 p.m.	0:00:43	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25406	17/06/2004	4:42:03 p.m.	0:02:07	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25407	17/06/2004	4:45:17 p.m.	0:01:04	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25408	17/06/2004	5:05:29 p.m.	0:01:16	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25409	17/06/2004	5:06:49 p.m.	0:03:01	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25410	17/06/2004	5:26:24 p.m.	0:00:38	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25411	17/06/2004	5:33:39 p.m.	0:01:45	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25412	17/06/2004	5:38:55 p.m.	0:02:50	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25413	17/06/2004	5:44:30 p.m.	0:05:19	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25414	17/06/2004	5:51:58 p.m.	0:01:10	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25415	17/06/2004	5:51:59 p.m.	0:00:49	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25416	17/06/2004	6:00:31 p.m.	0:00:32	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25417	17/06/2004	6:43:10 p.m.	0:03:01	LOAN	Thucydides	SLDWORKS.exe	P051-001			
25418	18/06/2004	7:30:40 a.m.	0:01:13	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25419	18/06/2004	7:35:45 a.m.	0:01:03	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			
25420	18/06/2004	7:38:52 a.m.	0:06:46	PC6	Francesco Balbi di Correggio	SLDWORKS.exe	P051-001			

Figure 24. Descriptive file workflow

In addition to identifying individual files, all files associated with a particular project could be determined from the metadata collected (caveat; only so long as usual enterprise protocols were followed – human nature often precludes 100% compliance with all extant rules), these files included all electronic communication, files created etc; all are date and time stamped. For example, see Figure 25 which details a portion of the files associated with a project entitled “P051”.

It was found possible to create a descriptive representation of a product development process based on the interactions of participants with the product data created by sorting and filtering the collected data. This chapter has detailed the extraction of metadata from a process viewpoint. This viewpoint necessarily excludes certain functions offered by the current product structure focused PDM systems.

Microsoft Excel - First 8 weeks (2)

File Edit View Insert Format Tools Data Window Help

1 page 1 question for help

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	A	B	C	D	E	F	G
3736	5/08/2004	4:35:56 p.m.	0:00:33 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116 - Sheet2	
3737	5/08/2004	4:36:31 p.m.	0:00:46 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116 - Sheet2	
3740	5/08/2004	4:37:17 p.m.	0:00:31 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116.SLDPR1	
3744	5/08/2004	4:37:50 p.m.	0:01:14 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116.SLDPR1	
3747	5/08/2004	4:39:30 p.m.	0:01:29 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116 - Sheet1	
3748	5/08/2004	4:40:59 p.m.	0:00:51 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116 - Sheet2	
3751	5/08/2004	4:42:59 p.m.	0:00:52 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116.SLDPR1	
3752	5/08/2004	4:44:04 p.m.	0:01:42 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116 - Sheet2	
3753	5/08/2004	4:46:44 p.m.	0:04:27 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116 - Sheet2	
3761	5/08/2004	5:10:16 p.m.	0:03:01 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-116 - Sheet2	
3763	5/08/2004	5:53:59 p.m.	0:00:47 PC7	Usamah Ibn-Munqidh	Acrobat.exe	P051-204-02.pdf	
3764	5/08/2004	6:00:37 p.m.	0:00:42 PC7	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-204 - Sheet1	
3766	5/08/2004	6:52:40 p.m.	0:01:58 PC7	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-204 - Sheet1	
3767	4/08/2004	9:09:38 a.m.	0:02:10 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-006.SLDAS	
3768	4/08/2004	9:15:58 a.m.	0:00:33 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3770	4/08/2004	9:16:32 a.m.	0:01:30 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713.SLDPR1	
3772	4/08/2004	9:18:02 a.m.	0:01:04 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3773	4/08/2004	9:19:17 a.m.	0:04:12 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3774	4/08/2004	9:24:03 a.m.	0:03:23 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3775	4/08/2004	9:28:08 a.m.	0:02:07 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3782	4/08/2004	9:30:50 a.m.	0:02:22 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3789	4/08/2004	9:33:19 a.m.	0:00:58 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3791	4/08/2004	9:37:11 a.m.	0:01:06 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-704 - Sheet1	
3795	4/08/2004	9:48:59 a.m.	0:04:45 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3796	4/08/2004	9:53:48 a.m.	0:00:35 PC8	Francesco Balbi di Correggio	SLDWORKS.exe	P051-713 - Sheet1	
3797	4/08/2004	10:10:19 a.m.	0:02:27 PC8	Francesco Balbi di Correggio	OUTLOOK.EXE	P051-713-0F Print	
3798	4/08/2004	10:13:06 a.m.	0:00:55 PC8	Francesco Balbi di Correggio	OUTLOOK.EXE	P051-713-0F Print	
3804	4/08/2004	10:14:06 a.m.	0:01:15 PC8	Francesco Balbi di Correggio	OUTLOOK.EXE	P051-713-0F Print	
3807	4/08/2004	10:15:24 a.m.	0:03:36 PC8	Francesco Balbi di Correggio	OUTLOOK.EXE	P051-713-0F Print	
3808	4/08/2004	10:47:33 a.m.	0:00:31 PC8	Francesco Balbi di Correggio	Acrobat.exe	P051-229-0C.pdf	
3809	4/08/2004	11:32:51 a.m.	0:03:01 PC7	Usamah Ibn-Munqidh	SLDWORKS.exe	P051-202 - Sheet1	
3810	4/08/2004	12:43:32 p.m.	0:00:33 PC7	Usamah Ibn-Munqidh	Acrobat.exe	P051-051-0A.pdf	
3811	4/08/2004	1:22:14 p.m.	0:00:32 PC8	Francesco Balbi di Correggio	Acrobat.exe	P051-509-0B.pdf	

Filter Mode

NUM

Figure 25. A set of “as created” Project files

These systems record attributes associated with the properties of the artefact (such as material and part relationships) in which relational databases are able to offer search and replacement functions. The metadata that is required to provide these functions is contained within the document data structure itself. The writer considers that the implementation of Module 2 described above (the file parser) would enable the recording of these types of metadata and thus enable the functions to be available to the methodology proposed above.

5.5 Analysis of Captured Data

In addition to the collection of metadata for providing information associated with the provision of PDM functions, information inferred relating to other areas of interest was able to be inferred from metadata associated with projects in the following areas:

- Computer use
- Software use
- File generation

5.5.1 Computer use

The monitoring software was enabled once a team member's computer was switched on. The elapsed time for an individual member's use of a computer during specified periods (hourly, daily, weekly etc.) was identified. The data also recorded those periods when the computers were on but not being used. Individual and team total times for both aspects were able to be collated. It was found that over the 22 weeks that the team were actively interacting with computers for an average of 47% of the time the computers were on. (Note that the data are subject to error as data was not received for a cumulative total of 2.5 days over the research period). The data enabled both high and low level software users to be identified as well as concurrent use of software programs. The data also identified the use or non use of computer power saving activities; this information was subsequently used to identify potential savings in electricity.

5.5.2 Software use

Elapsed time for an individual member's use of specific software packages during specified periods (hourly, daily, weekly etc.) was identified. Individual's cumulative use of specific programs, during specific time periods, were also identified. The research identified 18 separate programs that were used for a cumulative period of more than thirty minutes in a week by team members; these programs comprised the core of the software utilised. Over the 22 weeks the average use per week of the top six software programs for the team, was determined. A breakdown of this software use is presented in Figure 26.

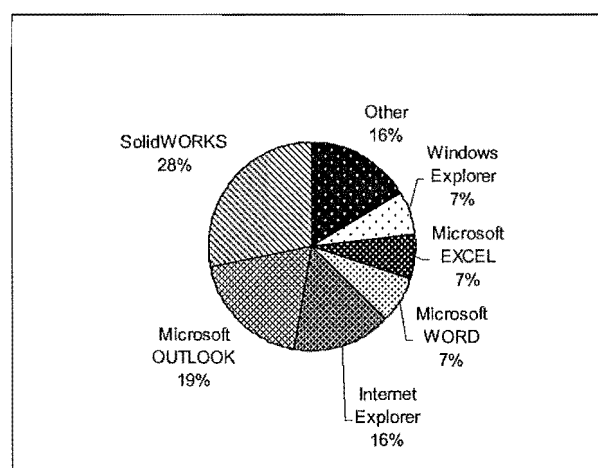


Figure 26. Software Use

Within each software package different activities were able to be determined. For example, when the CAD package SolidWorks was used, the monitoring software was able to distinguish between sketching, modelling and assembly activities performed by team members. The data enabled both high and low users of software to be identified as well as concurrent use of the software packages. This information was subsequently used for decision making related to the purchase of software licences. Older versions of software were also able to be identified.

The data enabled information relating to; the types of software used, period of use, when it was used, who used it and the functions that were used to be inferred. Of interest is that the monitoring software was able to record the order in which software was used throughout the day. During designing sessions it was possible to gather data relating to use of multiple programs for a particular project. In many sessions, team members could be seen to be using communicative software in conjunction with CAD activities to assist in development of the design hypothesis. Conceptual stages of design were punctuated by recourse to the world wide web (www) to search for related information, for example.

5.5.3 File use

Individual file use was also identified. That is, the name of the file in the software's active window was able to be determined by the monitoring software. In addition to the host enterprise used naming protocols, to associate the files to particular projects, other data management techniques were used. These techniques included the identification of file status (version, revision, process status) by location – i.e. files were moved between and stored in different locations to signify their current status. The data gathered by the monitoring software enabled files and documents to be tracked between users and the status of individual files identified through their location. It was found possible to monitor a single file as it moved between different authors and locations over a period of time. Data could therefore be gathered relating to the phases of the design process and the point of release of data to the next phase of a project could also be inferred.

The monitoring was not limited to file attributes. Access to information via webpages was also recorded. Team members were active users of on-line databases to assist design activities; access to bearing data, competitor websites, standard CAD models and other sites

was recorded. Furthermore, the timing of the access to these sources could be placed in context with other activities.

While most digital activities were able to be inferred from a combination of the available metadata and location data, in some instances, the identification of activities required further researcher investigation. These problems were a result of a) the lack of explicit metadata to classify the intent of tasks and activities and b) limitations in the metadata gathering functions offered by the available monitoring software. Both of these problems can be linked to the type and range of the metadata that could be recorded. The inclusion of explicit identification metadata in the data created by activities would enable the inference of different types of activities from the data; an increase in the range of metadata that could be monitored would further reduce researcher intervention as would implementation of the file parsing module described previously.

5.6 Process visualisation of the metadata

Tufte (Tufte, 1997), places emphasis on enhancing the representation and visualisation of data to assist acquisition of information by the reader. While information can be inferred from a list of the collected metadata gathered by observing the creation of data during a product development process, research also investigated the display of some of the information available from the metadata. To visualise the creation of data during a process the temporal attributes of the collected metadata were used and transformed into a three-dimensional model of the product development process. A 3D bar was created with nominal x-y axis units and whose length in the z axis corresponded to the period of time of active interaction with a file or document.

A proto-code was developed by the writer and this was transformed into a software application using a Python script (13kb, and coded by a colleague, Dr Jonathan Harrington). This application enabled the metadata to be transformed into a 3D object in a virtual world with the ability to be viewed using a standard web browser with appropriate plug-ins. All data objects were sorted, parsed by the script and assembled in a 3D world for analysis; individual projects were represented in separate 3D worlds and each world depicted document use along a single timeline. Multiple users were represented by a spatial separation in the x axis.

The proto-world depicted in Figure 27 below has a “floor” in the x-z plane and time flows along the z axis. (Note that the orientation of the axes are rotated in comparison to the theoretical model presented in the previous chapter and, in this example, documents that were interacted with for a period of less than 15 minutes were omitted – this was done for reasons of clarity). The bars represent the length of time a particular file is active. The text below the bar contains a record of the pertinent metadata (only just visible in Figure 27) and can include a hypertext link to the document or file. Once data are sorted a user can navigate the world and infer information relating to the descriptive process of the creation of files for a project.

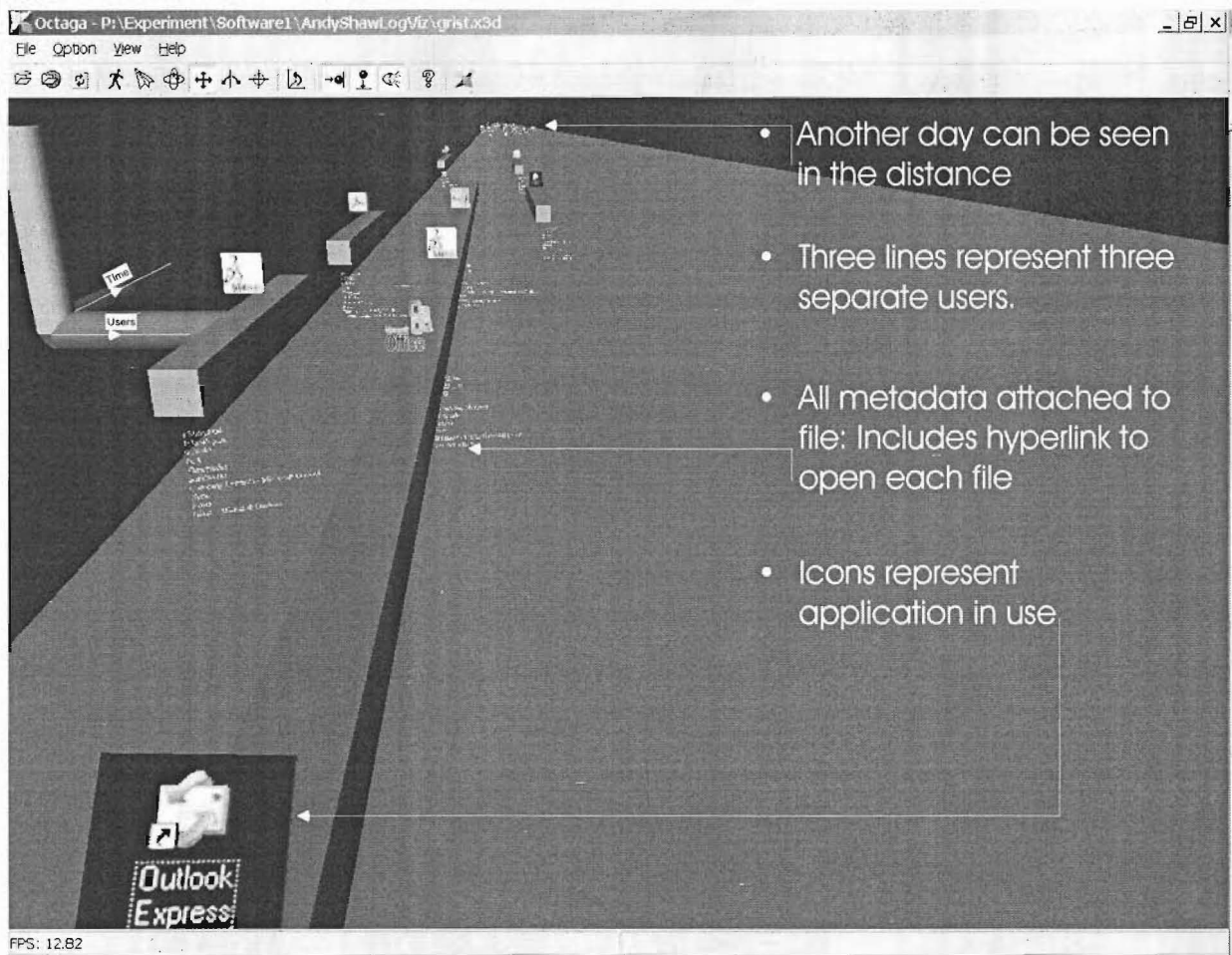


Figure 27. Virtual Process Data World Example

In Figure 28 overleaf, collected metadata has been filtered to identify a single document created as part of a project. Over five days, this single document (an excel file called “P121 BOM - ST300 Phase 4”) was viewed or amended by three different personnel. User interaction time with the document varied between 40 seconds and 31 minutes. Note also that

one user used two different computers to access the data. From Figure 28 it can be seen that the first user interacts with the document on five occasions between 9.53 am and 10.53 am, later that day a second user then interacts with the same document from 11.47 am to 12.02 pm. Interactions on subsequent days are also recorded.

	A	B	C	D	E	F	G	H	I	J	K	L	M
	Date	Start Time	Duration	Computer	User	Application	Active Win	Keystrokes	URL	Main Window			
1	16/08/2004	9:53:26 a.m.	0:02:16	PC6	Thucydides	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
2	16/08/2004	9:58:58 a.m.	0:01:01	PC6	Thucydides	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
3	16/08/2004	10:09:51 a.m.	0:01:21	PC6	Thucydides	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
4	16/08/2004	10:48:24 a.m.	0:01:30	PC6	Thucydides	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
5	16/08/2004	10:49:58 a.m.	0:02:00	PC6	Thucydides	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
6	16/08/2004	10:53:24 a.m.	0:01:04	PC6	Thucydides	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
7	16/08/2004	11:47:44 a.m.	0:00:55	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls [Read-Only]						
8	16/08/2004	11:48:57 a.m.	0:00:40	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls [Read-Only]						
9	16/08/2004	11:49:49 a.m.	0:01:10	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls [Read-Only]						
10	16/08/2004	11:51:07 a.m.	0:00:32	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls [Read-Only]						
11	16/08/2004	11:59:32 a.m.	0:01:22	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls [Read-Only]						
12	16/08/2004	12:01:13 p.m.	0:00:36	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls [Read-Only]						
13	16/08/2004	12:02:02 p.m.	0:03:09	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls [Read-Only]						
14	16/08/2004	3:35:58 p.m.	0:00:35	PC6	Thucydides	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
15	16/08/2004	4:39:32 p.m.	0:07:09	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls						
16	16/08/2004	4:50:51 p.m.	0:00:36	PC5	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls						
17	17/08/2004	10:20:43 a.m.	0:02:06	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
18	17/08/2004	10:51:10 a.m.	0:00:41	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
19	17/08/2004	10:56:59 a.m.	0:00:48	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
20	17/08/2004	10:58:10 a.m.	0:01:50	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
21	17/08/2004	11:00:00 a.m.	0:07:02	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
22	19/08/2004	9:43:43 a.m.	0:01:09	PC13	Xenophon	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4.xls						
23	19/08/2004	12:14:01 p.m.	0:00:37	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
24	20/08/2004	10:55:51 a.m.	0:30:23	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
25	20/08/2004	11:39:38 a.m.	0:31:49	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
26	20/08/2004	12:12:08 p.m.	0:08:24	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
27	20/08/2004	12:21:39 p.m.	0:01:07	PC15	Usamah Ibn-Munqidh	EXCEL	Microsoft Excel - P121 BOM - ST300 Phase 4						
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Figure 28. Sorted Metadata relating to a single document

This filtered data was then processed and transformed into 3D objects for visualisation. Figure 29 (overleaf) clearly describes the interactions between users of this document over a period of time.

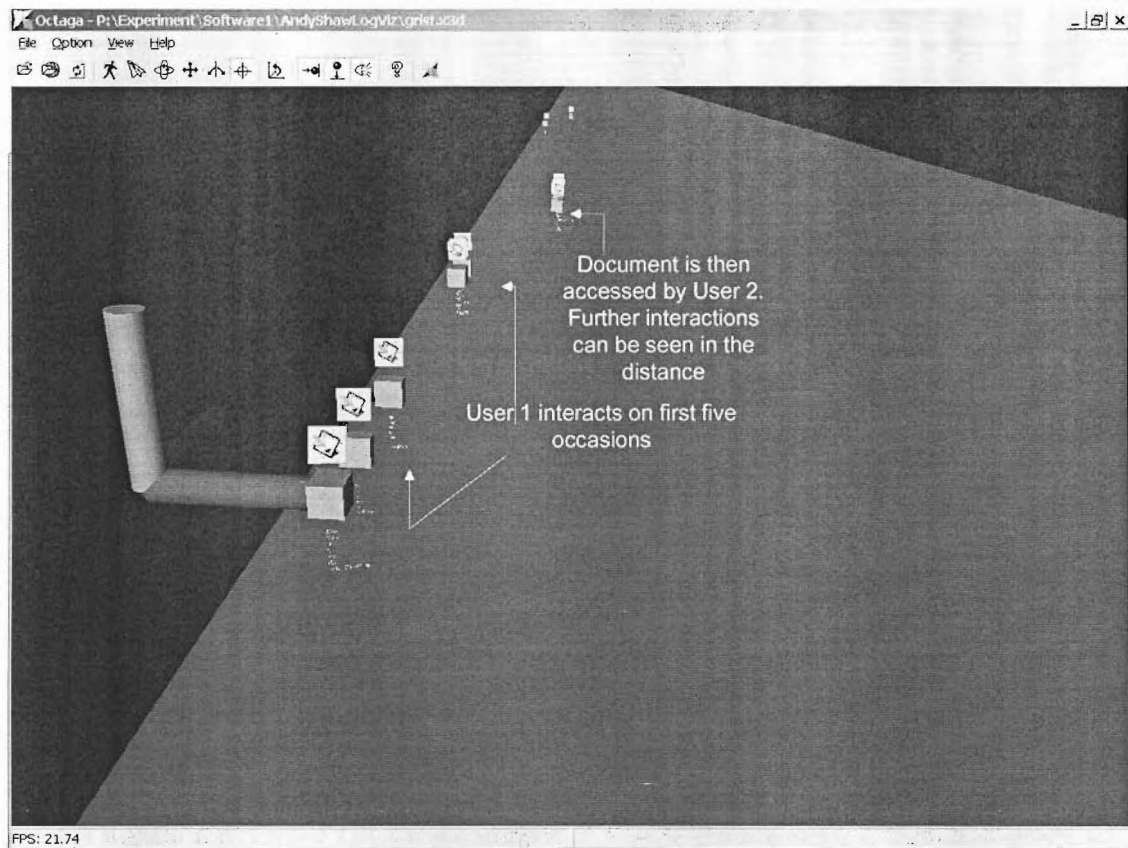


Figure 29. A single document moving between users

As recorded metadata are associated with each file, the world represents a visual description of the data created by participants and places these files in a temporal context. Directly linked to the monitoring software in real-time, it thus becomes possible for an offsite observer to view process and product development as it happens. For the purposes of managing the product data this descriptive representation could then be compared with prescriptive files required for a project and the differences between the descriptive and prescriptive models utilised to assist management of the project process.

5.7 Validation of research results

Theoretical models and experimental work have been presented. The aims of the research developed in the introduction can now be reviewed and the feasibility of automatically extracting types of metadata (identified from the conceptual model) from the computing environment and of using a comparison between metadata describing a real-time model of the created design documents and metadata describing a list of planned design documents to

visualise and control a product development process in smaller enterprises can now be assessed. The aims of the research were:

- To develop a new computer based method and/or tool that embodies the functions required by a computer based data management system.
- To develop a new computer based method and/or tool that provides a low cost, easily installed and maintained way to manage and visualise the data created during a typical product development process.

Management of Product Data was defined as the activities that are required to *manage* data within an organisation; a *Product Data Management* system then plans, organises, operates, controls and maintains the data pertaining to a product. The methodology proposed in this section has been shown to be capable of assisting the:

- *Planning of*: the required type, range and structure of the prescriptive documents associated with the product development process.
- *Organisation of*: the documents created into a process based descriptive representation of the project.
- *Operation of*: the tools required to identify and record metadata associated with the product development process.
- *Control of*: monitoring and scheduling the activities required to ensure the integration of data within a product development process through comparison between descriptive and prescriptive processes.
- *Maintenance and visualisation of*: the associations between document metadata in a product development process.

5.8 Summary

Preliminary results have identified that this methodology is able to provide metadata to enable PDM functions to be developed that compliment the existing location and stored metadata systems used by some SMEs, but that these functions are dependent on the configuration of an organisation's file and operating structure.

By recording file metadata through the use of monitoring software and the application of appropriate sorting, filtering and visualisation techniques, product data management functions detailed in Chapter 2 are able to be implemented. These are essentially the same functions that are associated with the PDM systems employed by larger organisations but employ different methods to record the metadata. Furthermore, metadata can be captured that refers to the activities that take place between the frozen product definition points that are used by current PDM systems. The captured metadata is also seen to be capable of providing data from which information can be inferred relating to non PDM functions.

The capture of a descriptive process and subsequent visual representation of data in a 3D world has offered the management team of the enterprise a new tool with which to interpret data created by the product development process. The structured metadata provides a descriptive representation of a monitored process that, in turn, may be of benefit to SMEs, as they do not utilise prescriptive processes to the extent that larger organisations do. This data may be compared with a prescriptive description of the data required for a process and the difference between the two may be utilised to manage the processes involved in a product development process.

Interpretation of the data has identified other advantages besides data management; e.g. the analysis identified data that was subsequently used to minimise CAD software licence costs as well as power savings. The visual display of the data in a 3D world has provided new ways to interpret the product data generated by the development process. It is considered that a representation of the prescriptive data could be easily introduced into the 3D world to facilitate the management of the process.

This research, while in its early stages shows promise as a cheap, resource-lean PDM methodology for SMEs, albeit requiring generalised organisational software configurations. The aims of the research with respect to the provision of PDM functions were shown to be satisfied by implementing the proposed software platform. Current limitations in monitoring software functions are due to the software products available and their design intent; it is considered that additional functions more suited to providing metadata for PDM purposes could easily be developed for a low cost.

Chapter 6. Conclusions and future work

This thesis has discussed the management of the data created by organisations during a product development process; specifically, the problems associated with the provision of PDM functions by Small and Medium Sized enterprises. This chapter will provide an overall conclusion to the research undertaken and consider areas for future work.

6.1 Conclusions

Data are created during all phases of a new product development process. Data management tools and methods employed by New Zealand SMEs were reviewed and electronic data was found to be created in all activities associated with the new product development process. The implementation of PDM systems by New Zealand SMEs however, was found to be minimal. It was concluded that the strategic, tactical and operational advantages to be gained from the implementation of these systems are lost to the majority of New Zealand enterprises. This lack of PDM functions is of concern, as current trends would indicate that the volume and range of data created by these organisations will increase in the 21st century as more and more applications become computer based.

The management of data is an essential component of success in the new product development arena; yet the review suggested that there was a low uptake of technologies to manage the data that New Zealand organisations create during a product development process. Current software to manage PDM systems were found to be inadequate for New Zealand SME needs: these organisations require new tools and methods to manage the data they are creating in ever increasing amounts. These tools must be cheap, easy to implement, operate and maintain, and fit within existing organisational and software structures.

In order to understand the role of data in organisations, definition of the terms and concepts involved were required, as extant literature appeared to use the terms data and information interchangeably. A relationship between data, information and knowledge was established and it was concluded that information could be inferred from data by an individual, dependent on their own set of beliefs and the amount of syntactic, semantic and pragmatic noise contained in the message.

Systems used to manage data were also required to be defined; current definitions being based on the functions a system possessed or the objects a system was required to manage. Furthermore, it was found that current PDM systems managed the data generated at the end of specific phases of the product development process, but that the data created during the generation of this data was not managed by the systems. It was concluded that if value could be added to the product development process through the management of the product definition data at specific points in the process then, recursively, further value could be added to the product development process by additionally managing the data generated between these points.

To investigate how SMEs might manage the electronic data they create, a fundamental conceptual model was required. Current research was found to be mostly in the areas of the PDM functions; while there was a wealth of research associated with enabling technologies for individual functions that comprise PDM systems, there was a lack of research that places the PDM systems within wider, necessary contexts. A metamodel was created to further investigate these contexts and the classes of data concerned. This model required the identification of the roles involved in the product development process and a representation of three systems: a model of the data created and communicated during interactions between roles in a process, a model of the organisation that included those roles, and a model of the process that the participants and organisation employed to develop new products.

To this end, the work of Ackoff and Emery, Beer, Garner and Hales was developed to produce a metamodel of an organisation implementing a product development process, accounting for the purposeful nature of participants (the *parts*), as well as the interaction of roles within the organisation (the *whole*). The metamodel was then used to assist the identification of data and metadata interactions during a product development process. This model was developed because a data management system suitable for SMEs could not be proposed without due consideration being given to the identification of the elements that must be managed within the relevant context.

Shortcomings in current PDM methodologies and their applicability to SMEs were identified and discussed; features unique to SMEs were found to hinder the implementation of the types of PDM systems that are currently used by larger organisations. Based on the developed model, a novel method for representing a product development process, through monitoring

the real-time status of product development document metadata, was then described and a software platform to implement this methodology presented.

To validate the software platform and methodology, monitoring software was utilised to identify and capture metadata generated by a typical operating system used by SMEs. This tool was recognised as having potential for incorporation into a methodology to provide PDM functions to be implemented by SMEs due to its low cost (less than \$200USD) and resource requirements (operating without user intervention and using widely available COTS common to most organisations).

The methodology proposed comparison between a real-time *descriptive* representation of the product development process and a *prescriptive* representation in terms of document use. Using simple PDM functions favoured by SMEs and recording file metadata through the use of monitoring software and the application of appropriate sorting, filtering and visualisation techniques, product data management functions were able to be provided that were similar to the functions associated with the PDM systems employed by larger organisations. That is, the methodology was found to be able to manage product data generated by these organisations.

The structured metadata provided a descriptive representation of a monitored process, which may be of benefit to SMEs, as they do not utilise prescriptive processes to the extent that larger organisations do. It was seen that this data may be compared with a prescriptive description of data required by a process and that the difference between the two may be utilised to manage the processes involved in a product development process. The method was also found to have the capability of providing metadata from which other, non PDM associated information could be inferred e.g. costing information and resource use. The ability to provide a historical record of computer based activities completed during a product development processes is inherent in this method.

Although the software tool and method were developed for SMEs the writer concludes that it would be equally applicable for use by larger organisations.

Information can be inferred from a record of the observed metadata created during a product development process; inferring information from raw data can often require specialist understanding and knowledge. Therefore, the research also investigated new methods to

display metadata to enable easier inference of the information potentially available. To visualise the creation of data during a process, the temporal attributes of the collected metadata were used and transformed into a three-dimensional model of the product development process. Compared to the product centric representations of currently available PDM systems, the capture of a process centric representation and subsequent visual illustration of grouped data in a 3D world offers management teams a new tool with which to interpret data created by the product development process. The ability to access this data in real-time and from a remote location in order to manage the product development process may offer further reductions in a product's time-to-market.

6.2 Future Work

A model to identify data creation and communication within an organisation has been developed. A methodology to extract data from which information can be inferred for the purposes of managing the product development process has been presented. Further research to investigate automated methods to interpret and analyse the metadata captured during interactions between roles is suggested. For example, the communication model predicts interactions between two roles during the development of a document: metadata created during these processes could be reviewed to ensure that all necessary interactions are complete. Furthermore, consideration should be given to automatic methods for the identification of the *types* of interactions: informing, instructing or motivating; such information will enable comparison between, and the management of, future projects. Future research should also consider the mapping of process metadata as an aid to the identification and development of standard processes within an organisation.

The visualisation of the metadata in a virtual world at present only includes descriptive metadata, the extension of this world to include a method that includes representation of prescriptive metadata would enhance the functions available as a management tool. Such metadata could be determined from project planning software where the outputs, in terms of documents, are prescribed; the captured metadata could then be easily included in 3D visualisations. Finally, the metamodel identifies all data interactions in a product development process and thus indicates potential metadata for use by systems employed by an organisation; the use of the methodology for recording this metadata in real-time should be investigated for purposes other than PDM within an organisation.

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Appendix 1. Technical Report No.58

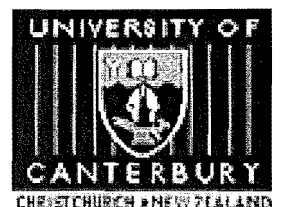
Technical Report

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**Survey of "Rapid Product Development for
World Class Manufacturing"
1999
Summary of Results
Report No. 58**

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Abstract

A survey of rapid product development practices in New Zealand industry in the 1999 year has been completed. This report presents a summary of New Zealand rapid product development practices based on a questionnaire survey of 107 companies and follow up on site interviews with 25 participating companies.

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1.0 Introduction

Shorter product development times are required because increased competition and shorter product lifespan are increasingly part of the global environment in which New Zealand companies compete. Higher lifetime sales and, by implication profits, equate to increased opportunity to invest in further new product developments, increased job security for the workforce and a better environment in which to foster further innovation.

For countries such as New Zealand that are attempting to move away from a reliance on the production of primary goods the need to conceive and manufacture products to compete in a global marketplace is becoming increasingly important. Whether this takes the form of adding value to the primary products, design and manufacture of new products or manufacture of existing products, the way in which we organise and operate businesses and the tools that we use to achieve this are critical to success.

Rapid product development is dependent on a number of activities within an organisation. These include:

- Organisational structure and culture
- Management of the processes
- Adoption and use of applicable technologies
- Skills and experience of development team

Survey of New Zealand companies

The objective for the research for the Public Good Science Fund was to investigate: "New Zealand manufacturers who introduce new products to international markets". Initial classes or groups were identified that could be used to search for and identify companies that fitted this definition.

- Exporters
- Manufacturers
- Manufacturing support industries
- NZ Industry leaders
- ISO 9001 companies
- CAD Users

Using the identified classes and industry types as a starting point various web-based databases were accessed and searched. The final database contained 680 companies that were identified as either manufacturers, or contributing to the manufacture of new products for international markets.

The questionnaire yielded a response rate of approximately 16 % usable replies. Respondents from this sample were asked if they wished to participate in a face-to-face interview and 73 responded positively. Interviews were held with 25 of these companies.

The questionnaire was addressed to the Managing Director as it was considered that senior company staff would have access to the type of information requested and would be familiar with the company's processes and procedures.

Survey questionnaire

The questionnaire consisted of three parts and a number of subsections that addressed activities associated with the product development process:

- Company and product classification
- Development of products
 - Selection of products for development
 - Organisational structure for design
 - Development of products
 - Design tools and methods
 - Technology
- Software in the Design process
 - Design management
 - Information Databases
 - Design representations
 - Communication and design information

Questions consisted of a mixture of “tick boxes” – giving a selection of closed statements to identify with, and “open boxes” – to record each company’s perceptions or replies to specific questions. The questionnaire consisted of twelve A4 pages and completion time estimated at 30 minutes.

Survey interview

Interviews were held at company premises over a period of six months. The interviews were mostly conducted with the person completing the questionnaire although other staff members who had an interest in the survey were sometimes present. Interviews ranged from one to four hours depending on time available. The interview was used to confirm the results recorded in the questionnaire. It also offered an unstructured environment to elicit information relating to the survey that was perceived difficult to obtain through the use of the questionnaire. An indication of the respondents’ company characteristics can be made from the following graphs. *

***Note: All chart column values reading Left-Right correspond with chart categories reading Top-Down.**

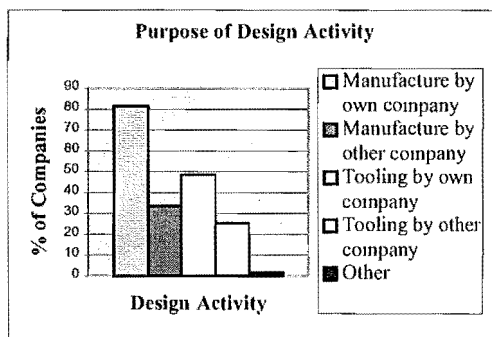


Fig. 1

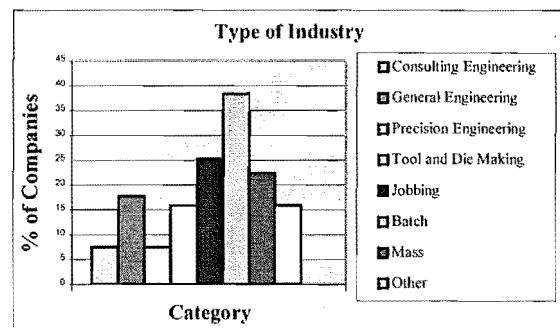


Fig. 2

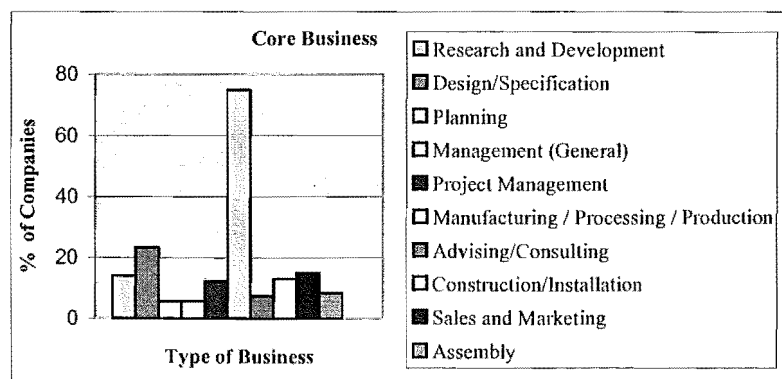


Fig. 3

Questionnaire and Interview Results

The study highlighted the fact that New Zealand industry comprises organisations that encompass a diverse range of product development and manufacturing activities. Furthermore, 81% of the organisations surveyed performed design activities for products that were partly or wholly to be manufactured by their own organisation.

The questionnaire and interviews have highlighted some pertinent information that is applicable to all industries that operate in New Zealand.

2.0 Company Characteristics

This section of the research was intended to serve two purposes:

- To gather data to relate characteristics of a company to the findings of the research.
- To determine whether there were some aspects of the product development environment common to companies.

There are three main findings from this section. These are related to:

- Subcontracted tasks
- Design Staff
- Quality Management Systems

Subcontracted tasks

Companies were asked what type of activities they subcontracted out. Eighty five percent of companies subcontracted at least one task and 64 % at least two. Tool making and tool design were the most popular subcontracted activities, although the type of work subcontracted depended on the type of industry surveyed. Interviews confirmed these observations. Typical of comments for reasons for subcontracting were:

- "We cannot afford to invest in these types of activities".
- This is a non-core activity.
- "...The capital expenditure to keep abreast of the field is large and it is more efficient to contract out this work".

The work subcontracted required specific sets of tools and knowledge that companies had decided they could not or would not consider having "in house". This has been interpreted as an indication of the early stages of a Knowledge Economy.¹ Specific sets of tools and knowledge require adequate resources to be kept current. Companies who have identified these activities as "non- core" frequently contract them out. Specific sets of knowledge and tools are the domain of companies who can afford to keep them current.

Design Staff

Companies were asked how many personnel were involved in product/tooling design activities. A majority (82%) of companies have 6 or less personnel involved in product/tooling design activities. This is a notable characteristic of New Zealand manufacturing companies, which are on average very small compared with those in typical industrialised countries. Furthermore, interviews suggested that larger companies tended to operate "product development teams" where participation by designers in these teams was not likely to exceed this number.

- It was suggested by some companies that smaller design/development teams offered a number of advantages for product development compared with larger overseas organisations. Suggested advantages included better communication and faster decision making. The perceived advantages to be gained were dependant on company characteristics such as size of organisation and type of product being developed.

¹ Knowledge Capitalism: Business, work, and learning in the new economy / Alan Burton-Jones. Oxford University Press. 1999.

Quality Management Systems

There was a high correlation between turnover, company size and exporting activity with the adoption of quality management systems.

- 89% of companies with a turnover greater than \$10m had implemented quality management systems complying with ISO 9001/2 and/or Ford's QS 9000.
- 66% of companies exporting more than 50% of their products had implemented quality management systems complying with ISO 9001/2 and/or Ford's QS 9000.
- 90% of companies employing 50 staff or more had had implemented quality management systems complying with ISO 9001/2 and/or Ford's QS 9000.

Anecdotal evidence suggests that users of Quality Assurance/Management systems implemented them for different reasons:

- The company had to implement a system due to external pressure, was unimpressed with the results and maintained the systems because it was required to.
- The company was under external pressure to adopt a system, did so and have since found that it has improved existing systems.
- The company adopted Q.A. Systems for their own reasons and used them to improve and qualify existing systems and found them an effective management tool.

Of note was the suggestion that the drive in the mid-80's/early 90's for certification to a quality standard by customers had decreased. That is, for many companies the primary reason for compliance was to meet tendering requirements (which stated compliance with a recognised quality system). This requirement was now not the primary reason for adoption or continuation of Q.A. systems. There are some organisations considering dropping current certification and it is evident that some new companies have not used external certification to provide proof of quality rather relying on their track record with their customers and internal quality systems to maintain quality. Anecdotal evidence suggests that interpretation of the standard and methods of implementation and auditing used in early quality systems to meet ISO 9001/2 may be behind the decision to drop the external certification of Q.A. standards in existing companies.

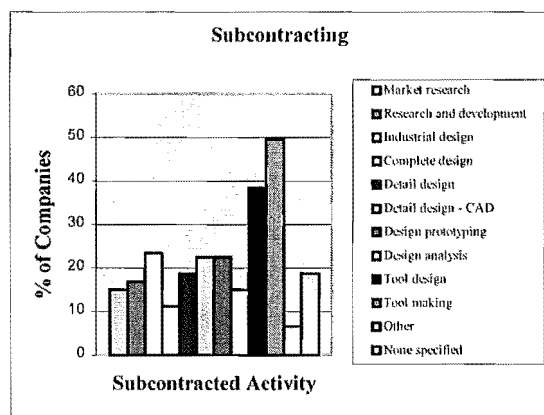


Fig. 4

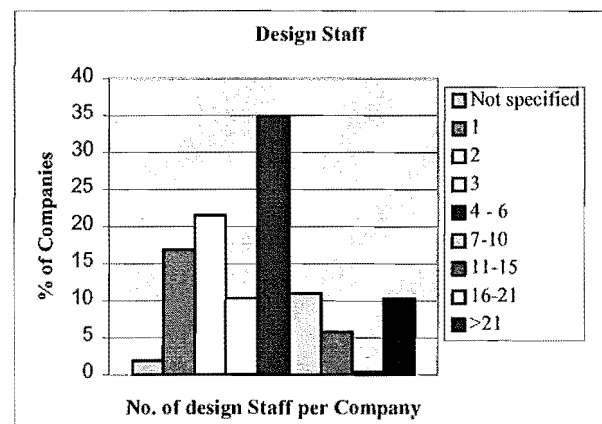


Fig. 5

Salient points.

- It is unlikely that all rapid product development activities are unlikely to be completed in-house and most companies tend to subcontract at least one product development activity. "Islands of Knowledge" are evident and the situation may be analogous to the "islands of automation" evidenced in the early 80's. The connection of these islands may involve some of the same problems associated with the "islands of automation".
- Companies recognise that certain activities (e.g. tooling, design, analysis, R&D etc) have high capital and infrastructure costs. If they are not core activities then they are likely to be contracted out. This has been interpreted as one of the first trends of a developing Knowledge Economy.
- Strategies for the selection of tools and processes for rapid product development in New Zealand should reflect the size of design groups and need to incorporate methods for assimilation of subcontracted work.
- There are perceived advantages associated with the smaller design and product development groups operating in NZ which make them competitive compared with overseas organisations.
- Exporting companies have considered it important to have formal management systems in place. The majority of companies were found to have in place systems that would comply with most provisions of ISO 9001:1994.

3.0 Development of products

Thirty five percent of respondents indicated that they used a procedure for the evaluation and selection of products for development. Of the group that indicated use of a procedure approximately two thirds had documented it in some form. Some companies provided samples of procedures, and analysis has shown that these procedures fell into two categories:

1. Procedures concentrated on detailing what paperwork or information was to be collected and recorded in the course of the activity. That is, the procedures were used as a check function to ensure that documents and records – which reflected activities within the process – were completed.
2. Procedures were at a more descriptive level and detailed more information about how the process was to proceed. That is, they recommended strategies, methods and tools to use, classified activities, responsibilities and decision points.

Few companies' procedures detailed information regarding how companies evaluated and selected products for development, rather they tended to concentrate on what happened from the point where the decision had been made to start the job. There may be several reasons for this:

1. The companies initial participation started at the Task Clarification stage.
2. The Design Proposal stage does not occur as part of a company's formal process but happens by more unstructured methods.
3. Companies saw an opportunity to secure the job and then looked at what it required. Whether they recognised that they would be required to participate in the Design Proposal stage is unknown.

3.1 New product development.

Companies were observed to fall into three groups with regard to New Product Development:

- Previous new product development (NPD) experience with documented formal strategies and procedures in place.
- Previous NPD experience with informal strategies and procedures in place.
- Little previous NPD experience and informal approaches to NPD.

Formal strategies and procedures in this area were observed to be mainly the domain of the larger New Zealand organisations. These companies had defined roles within the organisations dedicated to these activities as opposed to the smaller organisation where the activities were usually addressed as part of many functions by a small management team.

Smaller organisations performing NPD, or companies who were in a growth period from the successful development of an initial product, were less likely to have formal strategies and procedures. One aspect in common that these two have is the initial size of the team involved. This was typically small (less than six people). It is possible that the communication between the groups may supersede the need for formalised procedures and strategies within small groups. Indeed, companies that were interviewed and which operated without formalised procedures and strategies for the selection of new products often indicated that they "*had a plan*". The nature of this plan was not recorded.

Some of the companies intimated that some of their new products resulted from being "*in the right place at the right time*" and "*luck*". Additionally, other companies stated that they used intuition, experience, suggestions and feedback from customers as the methods they used to select products for development.

Several companies whose primary products were a result of being "*in the right place at the right time*" were now seeking new products and were implementing NPD programmes in order to find new products as the design life of their primary product draws to an end.

When a customer comes to a company with an idea for a product for development frequently the brief for the product is incomplete and the company continuing development must perform some of the tasks associated with the design proposal stage. Some companies have a function that includes refining the initial product specification. Interaction with customers at this stage depended on individual companies. The amount of refinement varied, as did the amount of responsibility afforded to the company.

Interviews also suggest that companies sometimes do not charge or write off costs associated with product development activities and use this as a method of attracting and keeping customers. In the minds of some customers further design required was considered to be part of the manufacturing process and the costs associated with the further design were the responsibility of the manufacturer.

Salient Points.

- The use of formalised strategies and procedures for the development of products is largely the domain of larger organisations. Smaller organisations stated they "have a plan" but this plan is unlikely to be of a formal nature. Questions remain about the efficacy of verbal intent vs. a formalised plan or procedure.
- It is evident that some product development is a result of being "in the right place at the right time". Furthermore "strategies" such as intuition, experience, suggestions and feedback from customers suggest that many organisations use unstructured approaches to product development.
- Companies introduced to the product development cycles at post Design Proposal stages were often found to feed back information that affected the conceptual stage. Approaches varied as to whose job it was, and sometimes costs were written off in the expectation that the company would retain the down stream work.

3.2 Establishing Customer needs

Customer specifications, observation and interviews were the most popular methods of determining customer needs. Very few organisations cited the use of tools or methodologies to determine customer (external or internal) needs. Use of tools such as Quality Function Deployment (QFD) was the domain of the larger organisations with specific design groups or design consultants.

The high incidence of Customer Specifications as a method may be a reflection of the type of activity performed by companies. However, many of the products developed depend on meeting customers' needs and the reliance on methods that are subjective may be a cause for concern. That is, companies placed reliance for determining needs on what information they were given or could observe as opposed to using methodologies to assist in the determination. Interviews suggested that outside large organisations the use of tools such as QFD was unknown.

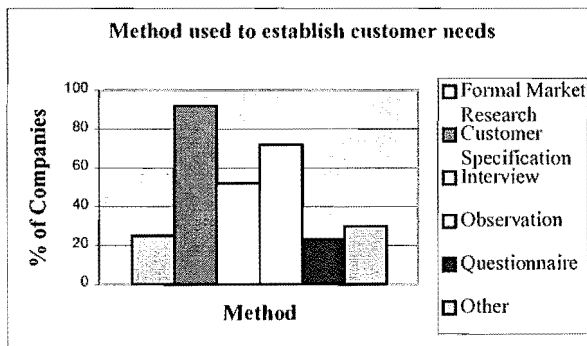


Fig. 6

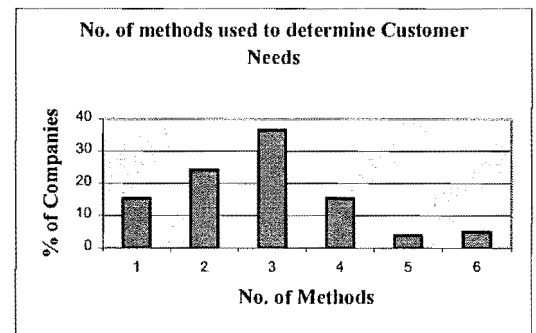


Fig. 7

Salient Points

- The most popular methods for establishing customer needs are: specifications, interviews and observations. Procedures are not commonly documented in organisations and there is variation in the intent of documented procedures ranging from identification of paperwork (representing activities) to identification of decisions, phases, resources and activities and paperwork. Additionally, many procedures start at the point where the product to be developed has been decided.
- When companies are completing designs initiated both by themselves and by customers, the ability to offer a total package is a great advantage. This is one of the tenets of agile manufacturing. Anecdotal evidence suggests that some companies are intentionally grouping themselves to offer complete packages to clients and that the Design Proposal stage may be spread over several organisations.
- Many companies compete in areas where knowledge of the customer's need is very important. The use of methods that are review and communication oriented, as opposed to formal tools to analyse or determine needs, is quite significant and may be cause for concern.

3.3 Organisational structure for design

This section of the survey was an attempt to determine organisational characteristics of companies with regard to product development. The following definitions of organisation types were used to identify company organisational structures²:

- Functional: Workplace is organised by function and authority rests with functional managers
Lightweight team leader: A project team leader exists but has little authority relative to that of functional managers
Balanced matrix: Authority shared between functional managers and team leaders, division of power is unclear
Heavyweight team leader: A strong leader has clear authority over team members on the project
Separate project team: Severs ties to functional departments

Very few organisations employed separate Project Teams, Balanced Matrix or Heavyweight Team Leader configurations for product development. Those that did were more likely to be larger organisations that had deliberately organised their teams in this manner as the result of a considered strategy.

Companies were found to appoint project managers in 68% of replies but responsibility for certain activities such as selecting personnel, responsibility for costs and primary responsibility for the project tended to lie with functional departments. That is, the majority of companies tended to employ Functional / Lightweight Team Leader structures.

Interviews suggested a predominance of Functional / Lightweight Team Leader organisation types in the larger (>20 personnel) companies. Significantly, individuals defined themselves as "*belonging to*" particular departments. Several organisations suggested that functional departments hindered company communication. Some companies suggested that although project managers were appointed as focal points for projects and given responsibility to organise work as it travelled through functional departments they had little authority in the functional departments.

In smaller companies it was more likely that management functions would be performed by one or two people who would direct the operation of the company, recognising the skills of the employees and determining tasks accordingly.

Mechanisms for maintaining contact with customers varied from company to company. Several methods were observed.

- Initial and continuing contact by a company representative (marketing/sales manager) who would act as the communication conduit between the customer and design/production departments.
- Initial contact by a company representative (marketing/sales manager) and then transferral to an internal company representative – the Project Manager.
- Initial contact by a company representative (marketing/sales manager) and then transferral to a company representative - the manager of the functional department working on the project at the moment.
- Initial contact with a company representative who was usually the person who initiated the work within the organisation – the design department. If no project manager were appointed the design department would often maintain contact with the customer.

Contributions to the product development team were most likely to come from three areas, Marketing, Design – mechanical and Production Planning. Many product development teams were likely to seek contributions from **less than** five different sources when planning their projects.

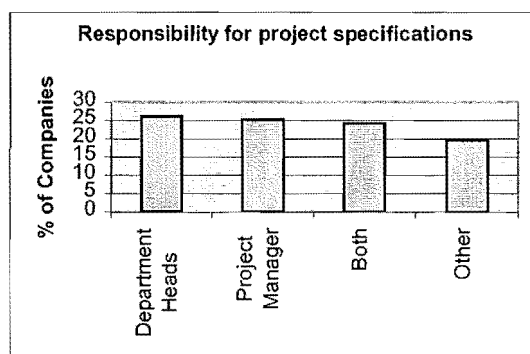


Fig. 8

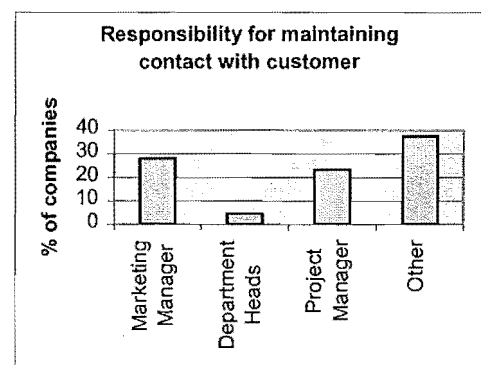


Fig. 9

² [Smith, Preston. G.; Reinertsen, Donald G. Developing products in half the time. 1995 pp 135 -141]

Salient Points

- The types of organisations encountered were found to be mainly Functional /Lightweight Team Leader organisations.
- Many companies felt the authority given to project managers was insufficient to let them effectively manage the project. There is anecdotal evidence that project managers are appointed to be a focal point for the project but that they do not have the authority to effectively manage the project.

3.4 Strategies for development of products

Companies were asked in the questionnaire what types of strategies they used to manage the development of products. The most popular strategy was for companies to have cross-functional teams. Interviewees considered a cross-functional team to be a group of people with different skills that could be brought to the development to the product. The team members were seen as "knowledge bases" to support the various functions and viewpoints contributing to the product development process.

Many companies said that their main strategy was "*working closely together*". This is one of the benefits from small product development teams.

Few (12%) companies stated use of Concurrent Engineering as a strategy to manage the development of products. Interviews with several companies suggested that this strategy involved the release of partial design information that was thought to be final so that subsequent tasks could be started thereby decreasing the lead-time for the completion of downstream activities. Few companies had rigid rules detailing the types of information to be passed. Information was reviewed at stages of the design process and a consensus agreement reached that it was an acceptable risk to release the partial information to the next stage. Formal methodologies for determining risks associated with release of information were not evident in the companies interviewed. Several companies interviewed said they had had a bad experience with this process when information that had been released was reviewed and changes found to be necessary. Subsequent design changes can result in rework negating any advantages gained by starting the task early. However it was felt that the benefits outweighed the potential risk. Companies tended to informally recognise what types of information were acceptable risks to release in an incomplete stage.

Other strategies identified fell into the category of design tools; QFD (Quality function deployment), DFM (Design for manufacture), DFA (Design for assembly) & Testing.

Many (more than 55%) companies employed a **single strategy** that they felt assisted the product development process.

Formal (documented) procedures for design activities were mainly used by the larger New Zealand organisations and those companies accredited to ISO 9001:1994. Even if a company used formal procedures for design they were also likely to use informal procedures. Interviews suggested that this was because people felt that certain design activities could not or should not be documented and that documentation of set activities would or could restrict the methods that they used. This was especially noticeable in organisations with ISO 9001, where it was sometimes considered preferable that some activities were not formalised as this allowed people to alter their methods without infringing their ISO accreditation. Many companies which were interviewed, and which operated without formalised procedures and strategies for design activities indicated that they "*had a plan*".

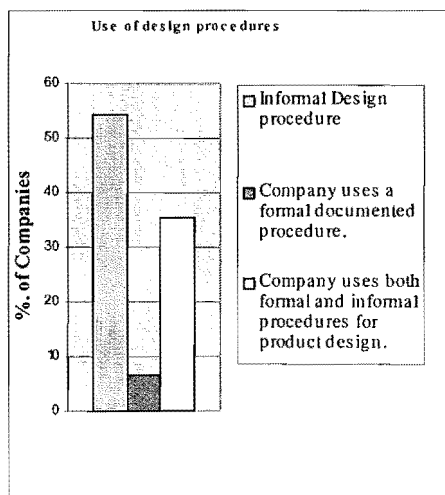


Fig. 10

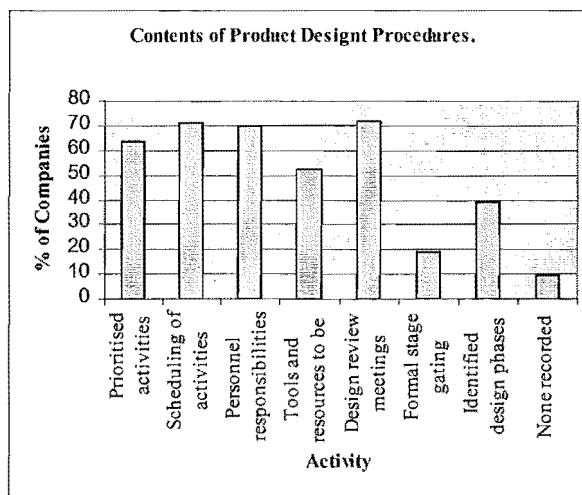


Fig. 11

Opinion was often divided within organisations regarding the need for structured approaches to tasks. In the absence of formal procedures, some staff thought they would be a good idea and would add structure to the tasks as a way of ensuring that all people would understand how things were done. Conversely, the opposing argument was that such procedures would stifle the design process and make things more bureaucratic.

Salient points

- *Some companies have identified that the skills of the people in the product development teams are important to the process. The identification of participants' skills is actively used as a strategy for product development.*
- *Also identified as a strategy for product development was the working environment of the personnel who perform design activities. Product development teams were usually small with participants enjoying close working relationships with each other by virtue of the size of the group (small number of participants), location of group members (physical nearness) and communications ease. Within teams, people felt that this communication replaced the necessity for formal procedures. People may either love or hate the idea of a defined methodology for doing things.*
- *Several companies released partial design information for downstream use in the product development process as a product development strategy. The type of information and perceived risks associated with its release were usually discussed but formal methodologies for these activities were not common.*
- *Procedures are not commonly documented in organisations and there is variation in the intent of documented procedures ranging from identification of paperwork (representing activities) to identification of decisions, phases, resources and activities and paperwork.*
- *Reasons for non-formalisation of design procedures included not wanting to restrict possible methods or solutions and difficulty in describing certain design processes in a documented format. There is an interesting perception in some companies that documented procedures cannot be disputed and must be followed. Some companies, rather than describe and document the dynamic nature of some processes, commonly chose not to include them. This may be an indication that the intent or perception of procedures in some organisations is focussed more towards "policing" activities rather than as an aid to support activities.*

4.0 Design Tools

Companies were presented with a list of design tools and methods based on a similar survey conducted in the United Kingdom. Respondents were asked to indicate what types of tools they used, whether the tool was paper or software based and at what stages of the design process the tools were used in. By far the most popular tools over all phases were:

- Brainstorming.
- Design review meetings.
- Product Design Specifications.
- Benchmarking of competitor products.
- Design mock-ups.

The use of tools is depicted in Fig. 12.

As a final question the respondents were asked their perception of the contribution of the tool to the design process. Respondents were asked to score the contribution of a tool to the design process using:

0 = No contribution...3 = Strong Contribution.

Results are summarised in Fig. 13.

Compared with a 1996 United Kingdom study New Zealand industry appears to make far less use of formal design tools

and methodologies.³ On average there is 25% greater use of these tools and methods by United Kingdom companies compared with New Zealand companies.

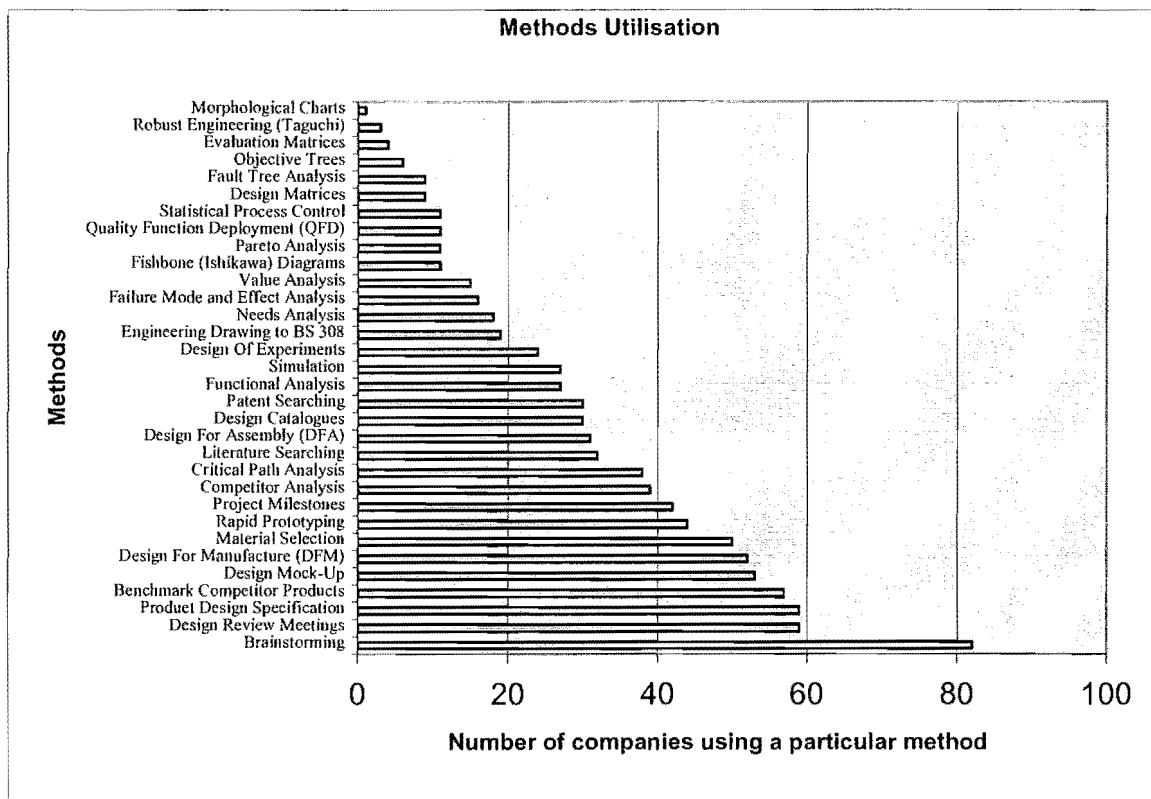


Fig. 12

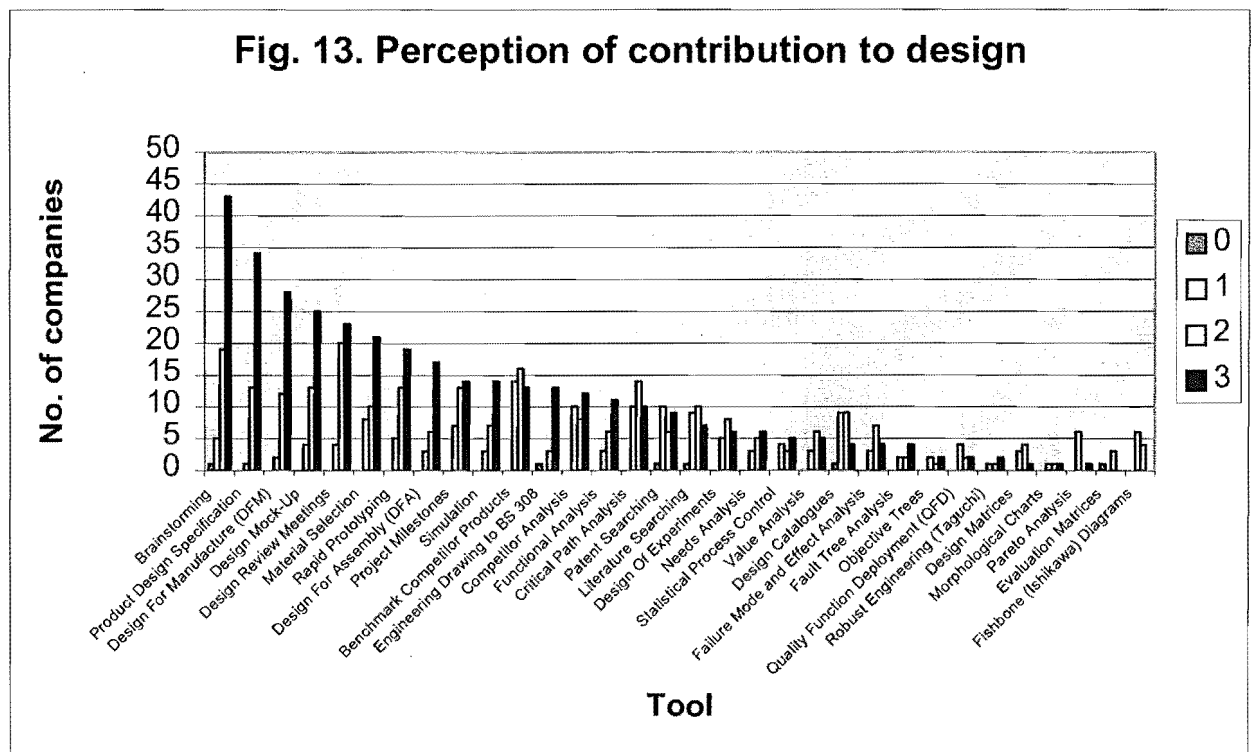


Fig. 13

³ The Utilization Of Product Development Methods: A Survey Of UK Industry. C.S. Araujo et al. *Journal of Engineering Design*, Vol. 7 No. 3. 1996.

The interviews brought into question the validity of the responses to this part of the questionnaire. All of the methodologies listed have very precise meanings and in most cases a defined procedure for their application. During the interviews it became apparent that while designers may have heard of these methodologies and claimed to be using them, very few had the detailed knowledge to apply them correctly. A good example of this is Design for Manufacture (DFM). When interviewees were asked about their use of this methodology it was found rather than the formal methodologies described in the textbooks, DFM was interpreted as simply including the manufacturing viewpoint during the design process. Similarly, interviewees, when asked about brainstorming, indicated little use of the formal methodology. Brainstorming in New Zealand consisted of a group of people gathering and talking about possible solutions as a method of generating ideas. These ideas were sometimes recorded and evaluated at the end of the session. Design Review Meetings consisted of regular review meetings to discuss the current status of the project and make decisions that were required for the project to proceed. Product Design Specifications were felt to be very important as they "set the scene" for the design.

Two types of rapid prototyping were in use:

- NC and CNC machining of prototypes..
- Layer building techniques such as stereolithography (SLA) and laminated object modelling (LOM) etc.

One of the more interesting methods involved a design team with access to a mill, which was basically used as a printer connected to the CAD package. This arrangement allowed expressions of design to be modelled in house in a rapid manner.

Most common was the use of stereolithography to create models. Interviewees gave a mixed response with regard to use of this tool. Some found access to rapid prototyping restrictive, that is, turn around time for the complete model was too long and the cost prohibitive. At least one organisation identified rapid prototyping as a bottleneck in their toolmaking process.

The second group felt exactly the opposite and cited good access to rapid prototyping in Australia and New Zealand, turn around times suitable for their needs and the activity cost efficient.

Salient Points

- *There is a weak correlation between the number of tools used within an organisation and the size of the organisation. A further correlation between the type of design activity and the number of tools used was slight.*
- *The tools that companies found to be of most benefit are all oriented to the review and communication of information within individual design phases.*

5.0 Technology and the use of Computers.

The questionnaire and interviews asked respondents in what areas of technology and the use of computers they had problems. They are summarised as follows.

Computer technology and Software

- Cost of software and training.
- Access to software support and training.
- Lack of access to software and Internet.
- Problems with or lack of integrated software and systems.

Hardware eg. Engineering Components and OEM Equipment

- Information about and sourcing of new equipment and products.
- Finding suppliers – the Internet is too broad
- The (lack of) range of products available locally.
- Cost of new equipment and products.
- Lack of access to advanced analysis.

Manufacturing Processes

- Access to advanced analysis, new processes and supplier information regarding processes.
- Cost with regard to smaller runs to make economic.
- Lack of IT support.
- Access to skilled and optimised tool making and injection moulding processes.
- Access to new electronic component assembly/processing techniques.
- Capability of work sourced in New Zealand is falling behind what is available in other countries.

Companies were asked about their strategies for the adoption of technology. Most New Zealand companies have informal approaches and strategies to guide their adoption of technology. Identification of personnel with the responsibility for monitoring technology was defined in less than 35% of companies.

One discussion on manufacturing processes suggested that because of the inability to keep up with rapidly changing technology New Zealand might soon lose the capability to manufacture some components for the burgeoning electronics industry.

Alliances.

Companies were asked to detail whether they had formed alliances to enable other organisations to be part of their process. Fifty percent of companies that replied indicated that they had formed an alliance of some sort. Of the 50% that indicated an alliance of some description:

- 30% had some sort of formal procedures detailing how the alliance is controlled.
- 35% had monitoring and enforcement plans.
- 46% had established formal software and communications systems.
- 80% had more than one alliance partner.
- Most businesses indicated they could continue in business without the partner.

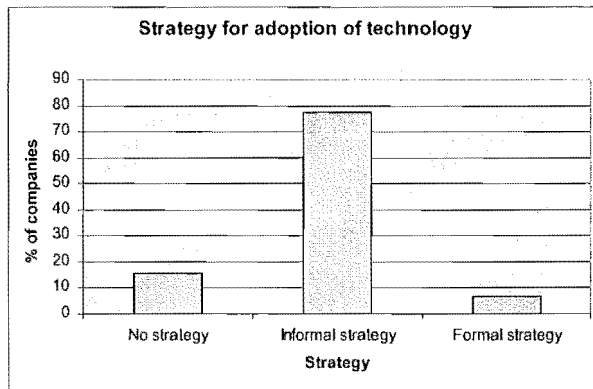


Fig. 14

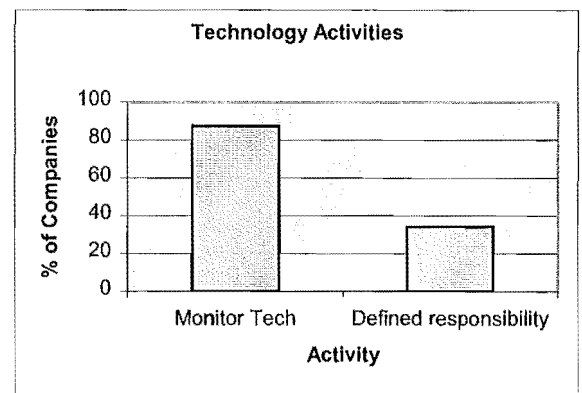


Fig. 15

Salient Points

- *The majority of problems with technology can be summarised as cost, access and training issues.*
- *Many New Zealand organisations have an informal approach to strategies and responsibilities for the monitoring and adoption of technology within their organisations. Frequently this falls to "someone who is interested" or "the boss". In this fast moving world this may not be an adequate response.*
- *The majority of product development projects are unlikely to be completed in house. There are several reasons for this and it is clear that New Zealand companies are placing emphasis on outsourcing services.*
- *The increase of working relationships with suppliers of services for mutual benefit is said to be one of the signs of a Knowledge Economy.⁴*
- *The survey has shown that New Zealand companies are outsourcing many of their non-core activities. This trend looks set to continue. The mechanisms that are used to control this type of work are mainly informal for the majority of companies. The lack of formal mechanisms behind the provision of goods or services such as communications, disputes and monitoring within alliances in this growth area needs to be addressed.*

⁴ Knowledge Capitalism: Business, work, and learning in the new economy / Alan Burton-Jones. Oxford University Press. 1999.

6.0 Design Management and Information Databases.

Storage of Product Data was paper and electronic based with a mixture of both methods being frequently used. Companies routinely had management systems for drawing databases, however the extension of these systems to include **all** product-related data was not common.

Most frequently, individuals working on projects were responsible for the collation of data relating to the tasks that they have completed. Whilst paper documents were stored in some sort of filing system whose rules were apparent to most users, people tended to store electronic documents in a system known only to themselves. Given the increasing migration to the electronic creation and storage of documents the survey found very little use of Product Data Management or similar software for the control of documents within companies' systems.

Many respondents recognised that "some method of organising these files needed to be addressed" but few companies had procedures for the identification, storage and amendment for all types of data associated with a project. Many respondents admitted that they had problems finding Product Data Files in the absence of key personnel. Information stored was *application specific* and *product specific* but **more likely to be stored as employee specific**.

Another aspect of relevance to rapid product development is the fact that companies, when moving quickly, have a tendency to leave paperwork (or the electronic equivalent) until there is time to complete it. With the rapid development of products, paperwork is going to have to be completed so that it is available for release both during the production and upon release of the product itself. This is especially true for data that is circulated outside the company such as product data to subcontractors and owners' manuals and troubleshooting guides to be released on the WWW to correspond with the launch of a product.

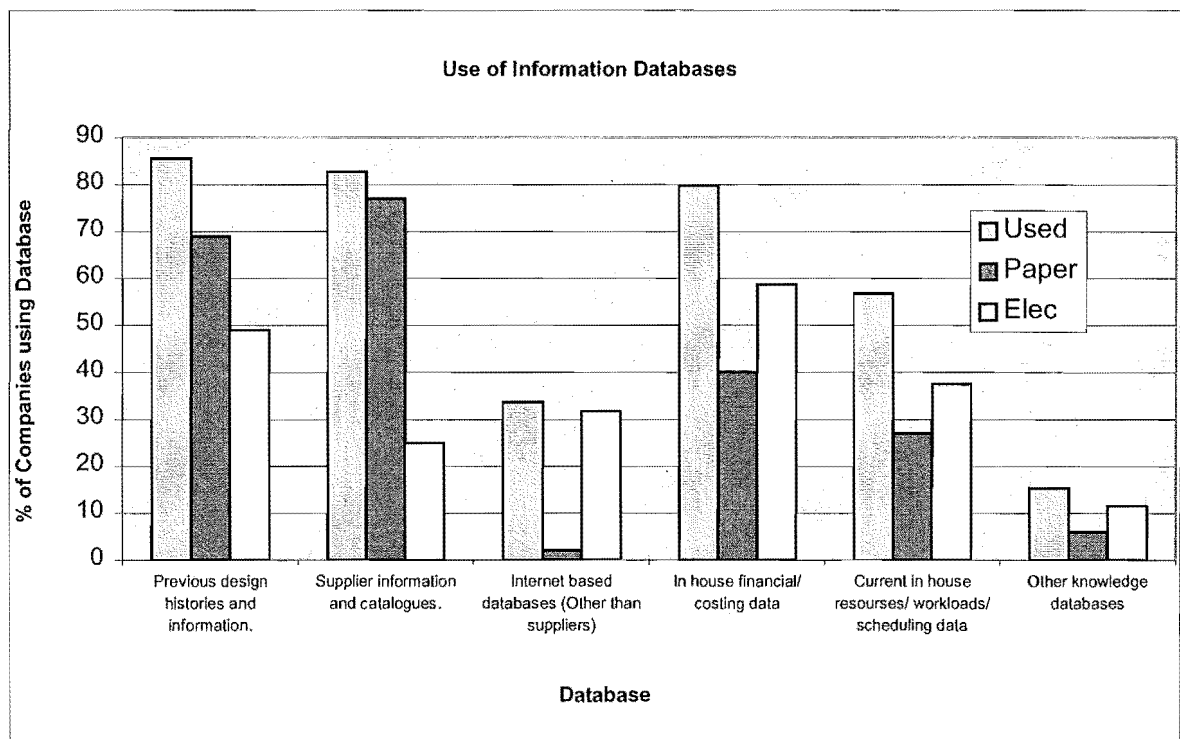


Fig. 16

Salient Points.

- There is increased access to databases through electronic formats, whether supplier databases or internal databases.
- More companies are moving to the electronic storage of documents and files. There is little evidence that this data is being stored in a secure and consistent manner as companies migrate from paper to electronic storage. Information was found to be stored as both application and product specific but was more likely to be **employee specific** in the absence of any formal systems.
- There is a tendency for companies when rapidly developing products to leave the paperwork until the end of the project, when it is perceived that there will be more time to complete it.
- There was little evidence found of the integration of application data. The use of Microsoft® products e.g. MS Office® was wide-spread and afforded integration within some environments but many companies used Enterprise Resource Planning (ERP), financial, project planning and supplier databases that were unable to be integrated. Several companies were looking at integration of packages to enable the seamless translation of information within applications but success in this area was not high.
- Companies appeared to have moved away from the in-house programming of applications to the purchase of vendor software. This software falls into two categories – Tailored for the use by software vendor and used as-is by the company with some tailoring by the user. Smaller organisations tend to use the second method.

7.0 Representation of Designs

The sample group identified trends in the use of design representations within the identified design phases as follows:

- Highest use of drafting and sketching in the Design Proposal stage, use then reducing through the remaining stages.
- Decrease in overall use of tools in the Task Clarification stage
- Increasing contracting-out of work as the design progresses.
- Use of Parametric Feature Based Solid Modelling (PFBSM) through out all stages of the design although some organisations are using it only in the latter stages of design and some in initial stages only.

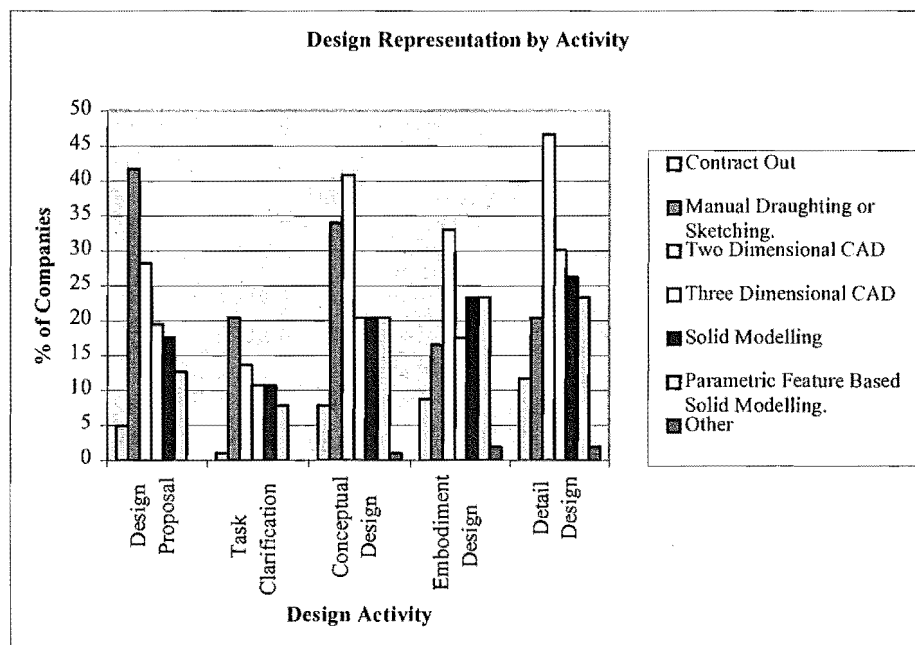


Fig. 17

There was a noticeable use of dual software platforms in some organisations. This has happened as companies migrated to newer platforms, moved from 2D or 3D CAD to a solid modeller or used different packages for different purposes. Interestingly, older platforms were frequently kept as the cost or benefit of migrating current designs to the new platform was seen as unwarranted. Almost 30% of respondents had two or more systems in operation. Use of systems was also associated with design stage in some companies. For example, one type of system would be used for the initial design phases and another to complete the detail design. Progressions from Parametric Feature Based Solid Modelling and to 2D/3D CAD and visa versa were observed.

The use of Parametric Feature Based Solid Modelling in the conceptual stages to produce rendered images for marketing purposes was noted. Top Down methods were the preferred methodologies for this stage. When later design stages were started, it was not uncommon to find the complete model restarted from scratch. Reasons cited included the time between phases and/or change in author – unless explicit notes are kept as to the design intent of the original model, interpretation of the model may take too long and it is quicker to start again. This is typically true of assemblies (used in the Conceptual Stage) where the rationale determining links between objects may be lost.

Top down and Bottom up design techniques for Parametric Feature Based Solid Modelling are used interchangeably in some organisations. Designers appeared to select methods based on the task at hand and the methodology they have adopted.

High-use and well-trained CAD operators appeared to get the most benefit out of the use of CAD products. These people had frequently developed their own methods for using the systems as opposed to an accepted company standard method.

Once the purchase of the system has been made few organisations were seen to continue benchmarking their tool against other competitors or the upgraded version against the current version. High end processing is still not a cheap pass-time and the activity of benchmarking to assess current systems does not appear widespread. Interestingly, problems associated with the speed and capabilities of packages were perceived to be attributable to the hardware platforms rather than the capabilities of the software. Upgrades of CAD products at a rate of every 6-9 months are a concern for some management. They cited cost and lost productivity caused by retraining requirements.

Companies were asked what problems they had with methods for design representation. The following comments were made:

Problems:

Solid Modelling

- Inadequate hardware platforms
- Customers will not always wish to commit to the cost of this process. "Too time consuming to use 3D CAD and solid modelling".
- Cost of Training in Software use and cost of migration to new packages or updates

Parametric Solid Modelling

- "Too slow, too complex, too inflexible."
- "Not cost effective"
- Development of methods for specific tasks/types of problems is required.
- Incompatibility and lack of integration with other company systems and external suppliers and customers.
- Cost of Training in Software use.

Contracting out work

- Costs associated with subcontracting.
- Subcontract vs. Purchase when demand for use is unknown

Manual Drafting

- Methods such as drawing overlooked because they are paper based.

Salient points

- *Lack of training and the inadequate provision of resources were main reasons for dissatisfaction with CAD packages. One high end user estimated that the resources allocated to training should be at least equivalent to the cost of the software platform itself.*
- *Respondents indicated it frequently “cost” more to model in a Parametric Feature Based Solid Modelling platform and sometimes the type of work did not warrant the use of this type of approach.*
- *There is evidence of methodologies emerging for different applications within the Parametric Feature Based Solid Modelling platforms. High users tended to develop personal methodologies for different types of design activities.*
- *After purchasing CAD products, very few companies continue to benchmark their products for performance.*

8.0 Analysis of Designs

Thirty nine percent of companies surveyed used software for the analysis of designs. Of the software analysis tools used the most popular were Finite Element Analysis (FEA) and Injection Mould Analysis. There were two main reasons given for the non-use of analysis software: high cost and lack of perceived benefit. Approximately one half of all software analysis activities were subcontracted whilst one third of the software programs used in house were integrated with CAD packages.

Salient points

- *Some companies felt that the cost of purchase, training and running software for injection mould flow analysis did not match the perceived benefits. Several companies quoted that there was a need to minimise the design process and spending time and money on analysis had no cost benefit: customers were often not willing to pay for the analysis and several felt that an experienced designer was equal to or better at analysis than some of the packages commercially available. They were “Not impressed by results”. Conversely, some companies who did use Injection Mould Analysis software reported large benefits from its use in the tooling design process.*
- *Many companies are not using software analysis tools because of lack of access or experience to apply them.*
- *In some companies the decision to use the tools was based on perceived risk or job interest value rather than as part of a company design process.*
- *The majority of companies used the analysis tools to check the results of design decisions they had already made. The emphasis on use of the tool was for confirmation rather than use as part of the design process to find possible solutions.*

9.0 Communications.

Companies were asked what methods they used to share/transfer electronic design data with other users. Email and disks were the most common methods but several companies noted that the transfer using disks was decreasing due to the size of the files being transferred and access to email and the Internet. At least one company is considering setting up their own FTP site to move data as the amount of traffic increases and dependence on an ISP starts to become an issue.

Companies were most likely to send files in their native format although IGES and STEP files were also used. Several companies select business partners on the compatibility of their software in attempts to avoid loss of data during conversion between formats as well as to promote continuity.

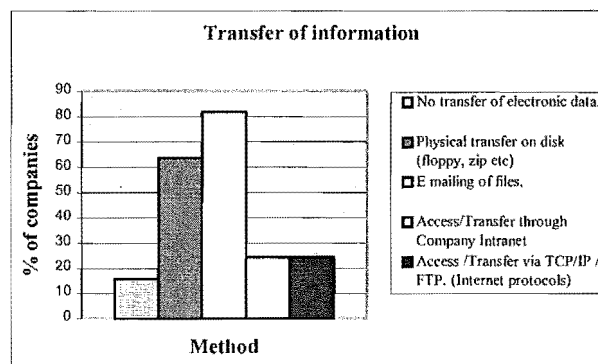


Fig. 18

Salient points

- *Data transmission between organisations is increasing. Several organisations are moving large amounts of data on a regular basis. Provision of resources for these activities will need to be reviewed within companies.*
- *Many organisations were observed to be opting for software compatibility as opposed to file translation when interacting with each other. Some companies cited bad experience with their use of neutral formats and translators.*

10.0 The Internet

Use of the Internet fell into four categories:

- Advertising or “presence”
- Search activities
- Customer information provision
- Communication

An interesting observation over the timeframe of the study was a proliferation of websites belonging to participating companies. These websites are mainly being used for advertising and companies felt that a “presence” on the web was important. Apart from filling the advertising purpose websites generally had very little to offer. Most sites consisted of:

- Company logo or graphic identity.
- List of past work
- List of capabilities
- Contact information

There was very little evidence of e-commerce or other customer oriented applications. Of applications sighted the most common customer service was access to on line operating manuals and/or parts databases. Most notable was that several of New Zealand’s major manufacturers are yet to establish a presence on the Internet.

The surveyed companies were using the Internet as a tool for product design activities in different ways. Examples included;

- *Analysis of competitor’s products services and prices:* Competitors products and services are available for view over the Internet. The access to this information affords a basis for competitor analysis when considering new products.
- *Searching for suppliers:* Supplier databases are becoming more common on line. Their use however was not that successful due to the proliferation of sites based in the USA. More uncommon items could be hard to find. Respondents recognised that certain techniques were better than others for different purposes. These techniques tended to be developed by users themselves and were not shared within organisations
- *Customer Information and Communication:* Access to product specifications, manuals, help lines and other **services** was a feature in some companies’ websites.

Several companies detailed problems with employees’ access to the web: Pornography and excessive surfing were the two most cited problems. Organisations are starting to set up procedures, monitoring or restricting the access to the web in order to take control. This is in contrast to some organisations where restriction to the web is very limited or nonexistent. Anecdotal evidence suggests that a fear of the Internet may exist in some management circles.

Salient points.

- *Techniques for the searching the web need to be developed and implemented within organisations. These techniques need to be developed for several different purposes.*
- *The current presence of most organisations on the Web is advertising based. The development of web centric customer based services that compliment the product development process will need to be a priority for organisations as methods of communication, planning and organisation migrate to web based environments.*
- *Organisations will need to consider and implement management and monitoring procedures and possibly codes of conduct for the use of the web within their organisations. The benefits of and access to the web will need to be evaluated within companies.*

11.0 Conclusions

The survey highlighted the fact that New Zealand industry comprises organisations that encompass a diverse range of product development and manufacturing activities. These activities are completed in organisational environments that differ widely in such areas as staff numbers, resources, planning activities, use of tools and management skills.

The following observations can be made of the product development practices of the sample group.

- Product development teams are small; this is seen as an advantage in maintaining a competitive edge.
- Toolmaking is seen as a bottleneck in the product development process.
- Low use of the Internet for business purposes other than advertising and supplier searching.
- Low use of formal strategies and procedures for product development.
- High use of informal structures, plans and strategies for product development.
- Many companies lack knowledge of the use of formal design tools and methodologies in the product development process.
- Low use of design tools and methodologies in the design process compared with 1996 United Kingdom figures.
- Low use of computer based product data management techniques.
- 86 % of surveyed respondents were using some form of computer aided design
- A surprisingly high proportion (65%) of the CAD users indicated they were using solid or parametric feature based solid modeling CAD packages.
- High instance of collaboration with external companies in the product development process
- Low number of formal alliances between companies.

We will use the results of this survey to direct our future efforts in research and technology transfer to assist in the development and adoption of rapid product development techniques. We make the following observations.

- It is unlikely that one single descriptive methodology would be sufficient to describe product development practices in New Zealand.
- Tools and strategies need to be oriented towards small design and product development teams.
- Tools and strategies need to facilitate the integration of several organisations into the product development process.
- Education and training is required to transfer knowledge of tools and processes known to bring benefits to the product development process.
- The growth of computer software to assist and replace paper-based tasks in the product development process needs to be supported by environments that facilitate the integrity, communication and use of the data and information generated. Additionally, methods for the innovative use of this software need to be developed and communicated to New Zealand businesses in an appropriate forum.
- In the near future we anticipate rapid product development techniques will be based on the Internet. New methods for planning and executing rapid product development in this environment need to be developed and communicated to New Zealand industry.

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John Raine
Ken Whybrew
May 2000**

Appendix 2. Selected Bibliography

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Appendix 3. Glossary

When management of the records and messages in a product development process is discussed, words to describe concepts such as data, information and knowledge are required. A review of literature concerned with the management of product data gives the impression to this author that the concepts of data and information are frequently used interchangeably. Clearly, the authors attach their own meanings to these words; however, there has been no attempt to ensure that the pragmatic aspects of the communication between the writer and reader are correct. Readers are expected to know what meaning is attached by the writer to the words “data” and “information”. Therefore, if this thesis is to be meaningful to persons other than this author, meaning attached to particular key words must be established. As Ackoff notes, and Britton and Garner reiterate:

“Defining is an aspect of the research process which all too few (*social*) scientists take very seriously. The meanings of the concepts are too often taken for granted. Yet definitions are essential as criteria for relevance of data used in evaluating variables and constants in all types of scientific statements: theories, laws, facts and decision models.” In addition, Ackoff points out that “...the progress of science, pure and applied, is as dependent on progress in defining as on progress in any other aspect of inquiry.” (Ackoff, 1968, Britton, 1978, Garner, 1991).

Similarly, in this thesis, a model is being developed with the intention of identifying the use of data in the integration of the beliefs of the participants in the product development process. It is intended that the model be used to investigate the management of product data within integrated organisations; as the models are symbolic:

“The symbols in a symbolic model represent variables, constants and the relationship between them. In its symbolic form the model represents only the structure of the problem and the phenomena involved. The model takes on meaning or content only when the symbols and the things which they represent are defined.” (Ackoff, 1968, pp.141).

“A definition, of course, is made up of words, and these words convey meaning.” (Ackoff, 1968, pp.146).

Originating from the biological General Systems Theory posited by Ludwig von Bertalanffy, (von Bertalanffy, 1969) a system can be open or closed. A closed system has no interaction with its environment but this thesis relates to an open system which consists of four components; objects, attributes, relationships and environments. Definitions will, therefore, be considered in terms of open system concepts. Firstly, definitions for the concepts Integration, Designing, Managing, Product, Data, Information, Knowledge and Understanding, as developed by Britton, Garner and Ackoff, are restated. Secondly, operational definitions for the concepts Metadata and Document are developed.

Integration

Garner determined that integration was...“The act of creating systems, whether systems of elements, or systems of activities.” (Garner, 1991, pp.24). He believed that Ackoff had captured the importance of this activity in the following statement:

“Performance of the whole depends critically on how well the parts fit and work together, not merely how well each performs when considered independently.” (Ackoff, 1974).

This thesis is investigating systems where data are used to integrate beliefs within the product development process; the integration of the beliefs of the participants is essential to the success of product development.

Designing

Britton noted the following essential properties of designing. This definition is extended to include processes and systems (*in italics*):

- Designing “is produced by a purposeful system”.
- “The product of designing is a message connoting the essential properties of an object *or a process or a system* which does not exist when the design is produced”.

- The designer “must not be aware of the complete set of properties in the design *or a process or a system* when he starts designing”.
- The designer “must not perceive a set of properties in his environment while he is designing, such that this set and those properties he starts with (given in his brief) make up the complete set given in the design.” (Britton, 1978, pp.30-32).

The activity of designing is instigated for a number of reasons. Stafford Beer, in his VSM (Beer, 1981), suggests that designing can be performed by three separate sub-systems which map to three of these prominent reasons:

Strategic Design: Occurs at the System Four Level (the self awareness of the organisation). That is, the system whose design functions generate products and/or physical processes and/or managerial processes which increase the probability of the enterprise to have the power to remain viable in future environments. Development is carried out to ensure a future for the organisation; new product and/or processes of this nature are examples of design activity at a strategic level.

Operational Design: Occurs at the System Three Level (the operational control level of an organisation); the development and optimisation of existing processes for the operation of Systems One (Production elements) and Two (Co-ordination elements). The re-design of production and/or management systems to increase productivity or to make efficiency gains is an example of design activity at an operational level.

Tactical Design: Occurs at the System One level. Designing new product and/or processes is undertaken as an activity for customers. An organisation that develops design solutions at this level makes design decisions on the basis of its extant design processes and procedures. i.e. the design of products and/or processes of this nature are examples of design activity at a tactical level.

The model developed in the next chapter represents a system of activities for assisting the integration of the beliefs of the role-players during product development, through the use of data at the System Three level (with reference to Beer's VSM). That is, the thesis deals with the operational design of a data management system used in producing tactical designs. However, it should be noted that a similar approach could be developed to produce models of the design interactions at the strategic and operational levels of an organisation.

Product Definition

Britton considers that if a purposeful individual (A) designs, in a choice environment (S), in a time period $t_1 - t_2$, then:

“ ‘A’ produces a message M_1 connoting two or more essential properties (Regli, Hu *et al*, 2000) of a concrete system(s) or object(s) which does not exist in any environment at time t_1 .” (Britton, 1978, Thesis III).

From this definition it can be concluded that a product definition is:

A message M_1 connoting two or more essential properties (Regli *et al*, 2000) of a concrete system(s) or object(s) produced over a time period $t_1 - t_2$.

Data

Ackoff defines data in the following terms:

“Data are symbols that represent properties of objects, events and their environments. They are properties of observation.” (Ackoff, 1989).

That is, data are symbols generated from the observation of the properties of objects, events and their environments. They include symbols that represent;

- The names and magnitudes of the structural properties of objects, of sets of objects, of structural environments and of events.
- The names and magnitudes of concepts.

With respect to product development; when a purposeful individual designs, data are generated from observation of:

- The properties of objects and events in the environment in which the designing occurs.
- The hypothesised properties (Regli *et al*, 2000) of a concrete system(s) or object(s) to be produced over a time period $t_1 - t_2$.
- The properties of the courses of action hypothesised to be required to achieve P_X .

Information

“Information is contained in descriptions, answers to questions that begin with such words as who, what, where, when and how many.” (Ackoff, 1989). Furthermore, Ackoff and Emery regarded information to be communications that change the probabilities of choice:

“A communication that produces a change in any of the receiver’s probabilities of choice informs him, and hence transmits information.” (Ackoff and Emery, 1972, pp.144).

In addition, Ackoff and Emery note that “messages are not the only source of information; one may also obtain information by perception.” (Ackoff and Emery, 1972, pp.153):

Perception; a response to a stimulus that also produces a change in at least one structural property of the respondent. Therefore, information may be inferred by an individual from data generated by observation.

A person that is informed by a communication does so in the context of their own internal model; that is, their own individual set of feelings and beliefs. It is clear that a given piece of data can provide different information to different individuals.

For example, if two individuals were given a piece of paper on which were written the following symbols: “HB 71 .A182”. One individual could receive this message and, given their own internal model that could interpret these symbols, be informed of the call number of

a book in the University of Canterbury library. A second individual, with no knowledge of the library's call numbering system, would not receive the same information.

Hence, recorded data *is not* information. Internal processes by an individual render data into information; they must *know* how to interpret the data.

Knowledge

The scope of this thesis is such that it will not delve into the management of knowledge within the product development process. However, an understanding of the management of data for the purpose of integrating organisational beliefs in the product development process will necessitate discussion of the part knowledge plays in the process. Ackoff & Emery state that knowledge has at least two different senses:

The first, "knowledge of use or courses of action" is related to the "Efficiency with which an individual can use a course of action to achieve an objective". That is, *knowing how*. (Ackoff and Emery, 1972, pp.46).

Knowledge is required to control a system: as Ackoff notes in a later address:

"Knowledge is know-how, for example how a system works. It is what makes possible the transformation of information into instructions. It makes control of a system possible." (Ackoff, 1989).

The second sense, "awareness or possession of a fact or state of affairs" relates to the individual's beliefs and awareness – what they "*know*". (Ackoff and Emery, 1972, pp.46).

Therefore, we must consider both senses of knowledge within the product development process and consider how the management of data and hence, information, contributes to each sense.

Understanding

It has been stated that data are generated by observing the properties of objects and events in the environment in which a course of action is performed. To obtain information from this data, a purposeful individual must understand:

“...that which is observed, no matter how carefully and no matter how accurate the record, is capable of being understood only in terms of projected consequences or activities.” (Dewey, 1938, pp.499).

Ackoff & Emery define understanding as; “The ability to efficiently adjust one’s behaviour to changes in the conditions that affect its efficiency.” (Ackoff and Emery, 1972, pp.47). In this sense it can be seen that the acquisition of data changes a person’s internal model which, in turn, can contribute to an adjustment of the recipient’s subsequent behaviour.

It is not necessary, for the purposes of this thesis, to define wisdom, but it should be noted that information, knowledge and understanding relate to a purposeful individual’s *efficiency* of choice in a given situation. By comparison, wisdom is related to the *effectiveness* of that choice.

Definitions: Metadata and Document

Another two terms that will be used in this thesis remain to be defined. Operational definitions for these terms will follow the form of Britton and Garner who utilised the first three stages of Ackoff’s operational defining procedure (Ackoff and Emery, 1972, pp.150). See Britton (Britton, 1978, pp.23) and Garner (Garner, 1991, pp.21) for details of the rationale behind the amended procedure which is reproduced below:

1. Examine as many definitions of the concept, past and present, as possible. Keep in mind the chronology of the definitions examined.
2. Try to identify the core meaning toward which the definitions seem to be evolving.
3. Formulate a tentative definition based on this core.

Metadata: Examination of definitions

The Oxford English Dictionary (OED) (Online, New edition: draft entry Dec. 2001), defines metadata in the following way:

Metadata n., a set of data that describes and gives information about other data.

The OED gives the following quotations for the use of metadata and appears to date an original entry from 1969:

“1969 Proc. IFIP Congr. 1968 I. 113/2 There are categories of information about each data set as a unit in a data set of data sets, which must be handled as a special meta data set”.

“1987 Philos. Trans. Royal Soc. A. 322 373 The challenge is to accumulate data from diverse sources, convert it to machine-readable form with a harmonized array of metadata descriptors and present the resulting database(s) to the user”.

“1998 New Scientist 30 May 35/2 With XML, attaching metadata to a document is easy, at least in theory.”

“The Product Data Management Information Centre (PDMIC) (PDMIC, 1995) glossary definition of metadata is: “Information about the data under PDM control.” (Contributed by Jeffrey W. Young, Director of Methodology, SDRC Metaphase)”.

Definitions can also be sought utilising on-line web based search engines: The Define function of the web search engine “Google” can be utilised to obtain internet based definitions. At www.google.com the string “define:metadata” gives the following result. (N.B. Google defaults to country of query, and results will change over time).

Metadata: Data about data, or information known about the image in order to provide access to the image. Usually includes information about the intellectual content of the image, digital representation data, and security or rights management information.

“Metadata: Definition: Traditionally: metadata has been understood as “Data about Data”
Example(s): a library catalog (sic) contains information (metadata) about publications (data) a file system maintains permissions (metadata) about files (data).”

Note that in the second definition metadata are described as “*information* about publications”. Metadata is a new concept – the OED entry for example is at present a draft; it has only recently been coined. The word is generally associated with the field of computing and is applied to sets of data created, stored and transmitted in a computing environment.

Metadata: essential properties

All definitions essentially concur that metadata is “data about data”. The descriptions further note that information may be obtained from this metadata (one definition defines metadata *as* information). Like data, metadata is generated from observation. If we choose not to observe the properties of a system then that data does not exist. Thus, authors frequently associate metadata with purpose; metadata is identified for a particular use. This is frequently because the information that can be inferred from metadata can be used, in conjunction with knowledge and understanding to make control of a system possible.

If we refer to the previous definitions of data and information, accept that metadata is “data about data” and that metadata is generated for a purpose. then:

Metadata: a definition

Metadata n., data concerning sets or classes of data.

Furthermore, it follows from previous definitions that information can be inferred from metadata.

Document : Examination of definitions

The OED (Online, New edition: draft entry Dec. 2001) defines a document in the following way:

document, n. Something written, inscribed, etc., which furnishes evidence or information upon any subject, as a manuscript, title-deed, tomb-stone, coin, picture, etc.

The OED gives the following quotation for the use of document and appears to date an original entry from 1727:

“1727-51 CHAMBERS Cycl., Document, in law, some written monument produced in proof of any fact asserted. The antiquity of the foundation of such a church is proved by a number of authentic documents”.

“1755 N. MAGENS Insurances I. 340 As an Authentic Document was required of the foregoing Declaration, I signed and sealed this to serve where occasion shall require”.

“1810 WELLINGTON in Gurw. Desp. VI. 290, I had got the emplacement of the whole French army of the 1st June which is a very curious document and gives a tolerable notion of their whole force in Spain”.

“1850 A. JAMESON Leg. Monast. Ord. (1863) 401 These frescoes have become invaluable as documents”.

“1877-9 F. WHARTON Law of Evid. I. II. ix. §614. 586 A ‘document’ is an instrument on which is recorded, by means of letters, figures, or marks, matter which may be evidentially used.”

The PDMIC glossary definition of document is “A set of data to be controlled and communicated as one single unit”. Contributed by Pierre Breuls of Eindhoven University of Technology.

As with the term metadata, several Web based definitions were obtained by entering the following search string into the Google search engine: “define:document”:

“Document: A document is a file that contains information that the user (you) can view or hear. It is most often a word processed letter, a picture, a sound byte, or something similar. Documents are usually created and edited using programs such as Microsoft Word, or Adobe Photoshop”.

Definition provided by Jerel Tomasello(<http://www.learnthat.com/define/d/document.shtml>).

It can be seen that the use of the word “document” has changed over three hundred years. Like metadata, the word has been ascribed a particular usage in the computer age. In this instance a “document” connotes a set of data that, when used in conjunction with the appropriate software, will present the data in such a way that information can be inferred.

Note that despite the much vaunted claims that organisations are progressing towards “paperless offices” paper based documents still exist. Thus documents can refer to both electronic and paper based data.

Document: essential properties

From the definitions presented above, the first essential property which may be drawn is that a document is a record of data. That is, a document is a device that records data and/or metadata. A second property is that information is associated with a document; information is inferred from the data or metadata recorded in the document. Several properties associated with computers are in use; that the document can be controlled and that the document can be utilised by a computer. This is the electronic version of the paper equivalent.

If we refer to the previous definitions of data, metadata and information, accept that a document can be paper or electronic in manner and that the contents are a record, then:

Document: a definition

Document n., a record of one or more sets of data and/or metadata.

Appendix 4. Published Papers

- [1] Shaw A. I., Aitchison D. R. 2002. *Education In The Use Of Design Tools And Methodologies For Rapid Product Development In A Global Information Society*. 3rd International Conference on Information Technology Based Higher Education and Training - ITHET 2002, July 4-6, 2002, Budapest, Hungary.
- [2] Shaw A. I., Aitchison D. R., *Education in management of data created in new technologies for rapid product development in SMEs*. Industry & Higher Education, 2003. Vol 17 (6): pp 423-430.
- [3] Shaw A. I., Aitchison D. R. 2003. *Education In The Management of Data created by New Technologies For Rapid Product Development in Small and Medium Scale Enterprises*. 4th International Conference on Information Technology Based Higher Education and Training - ITHET 2003, July 7-9, 2003, Marrakech, Morocco.
- [4] Shaw A. I., Aitchison D. R. 2003. *Real Time Rapid Product Development Process Data And Information Management For Smaller Enterprises*. 14th International Conference on Engineering Design, August 19-21 2003, Stockholm, Sweden. pp 505.
- [5] Shaw A. I., Aitchison D. R. 2004. *Rapid Product Development Data Management Education for Small and Medium Size Enterprises*. 5th Int. Conf. on Information Technology Based Higher Education and Training: ITHET '04, 31st May - 2nd June 2004, Istanbul, Turkey.
- [6] Whybrew K., Shaw A. I., Aitchison D. R., Raine J. K. 2001. *Use of Design Tools and Methodologies for Rapid Product Development in the New Zealand Manufacturing Industry*. 13th International Conference on Engineering Design, August 21-23, 2001, Glasgow, UK. pp 27-34.